

PB87-113247

Evaluation of Primary Air Vitiatioin for
Nitric Oxide Reduction in a Rotary Cement Kiln
Volume 1. Technical Report

KVB, Inc., Irvine, CA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Oct 86

U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/7-86/034a	2.	3. RECIPIENT'S ACCESSION NO. PB87-113247 /AS
4. TITLE AND SUBTITLE Evaluation of Primary Air Vitiatio for Nitric Oxide Reduction in a Rotary Cement Kiln; Volume 1. Technical Report		5. REPORT DATE October 1986
7. AUTHOR(S) R. C. Benson, S. C. Hunter*, R. A. Frohoff ^Δ , and N. R. Parker ^Δ		6. PERFORMING ORGANIZATION CODE
9. PERFORMING ORGANIZATION NAME AND ADDRESS KVB, Inc. 18006 Skypark Boulevard Irvine, California 92714		8. PERFORMING ORGANIZATION REPORT NO.
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3690
		13. TYPE OF REPORT AND PERIOD COVERED Final; 6/83 - 9/85
		14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES AEERL project officer is Robert E. Hall, Mail Drop 65, 919/541-2477. (*) Volume 1 only. (Δ) Volumes 2 and 3 only.		
16. ABSTRACT The report gives results of tests to evaluate combustion modifications for nitric oxide (NO) reduction and cement product quality in a pilot-scale long-dry-process cement kiln firing pulverized coal. The kiln is rated at 11.35 kg/s (1080 tons/day) of cement with a thermal input rate of 70.3 MW (240 million Btu/hr). Of the combustion modifications evaluated in previous studies, vitiation of the primary air with inert gas (nitrogen) was considered the best alternative for NO reduction on a pilot-scale kiln. As-found emissions (17 days of data, 89.75 hours) were about 3.6 kg (8 lb) NO as NO ₂ per 907 kg (1 ton) of clinker. The uncertainty of the as-found mean mass emissions is about 10%. Lowered excess air (LEA) decreased NO volumetric and mass emissions by about 15-20%. The percent reduction was established from a reference baseline of 1050 ppm (corrected to 3% O ₂) and a kiln exit oxygen of 1.82%. The NO volumetric emissions were lowered to 880 ppm (corrected to 3% O ₂) with a kiln exit oxygen of 0.7%. NO _x reductions during the short term nitrogen injection tests were about 25-30% with no adverse effects on product quality. Because of the interacting feed chemistry/kiln operations, it was not possible to clearly isolate the effect of nitrogen injection. For long term operation, flue gas recirculation would be more cost effective in achieving primary air vitiation.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Cements Kilns Nitric Oxide (NO) Combustion Pulverized Fuels	Pollution Control Stationary Sources Cement Kilns Primary Air Vitiatio Combustion Modification	13B 11B, 13C 13A 07B 21B 21D
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified 20. SECURITY CLASS (This page) Unclassified	21. NO. OF PAGES 401 22. PRICE

PB87-113247

EPA/600/7-86/034a
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EVALUATION OF PRIMARY AIR VITIATION FOR
NITRIC OXIDE REDUCTION IN A ROTARY CEMENT KILN

Volume 1. Technical Report

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ABSTRACT

KVB has been funded by the U.S. Environmental Protection Agency to conduct research for emission reduction from industrial processes. One phase of this research effort concerns NO reduction from cement kilns. Tests were conducted on a 1100 ton/day long, dry process cement kiln to evaluate the effect of primary air vitiation on NO emissions. Primary air vitiation was accomplished by injecting nitrogen gas into the primary air. As found, test results (17 days, 89.75 hours) prior to the nitrogen injection test were used to assess the inherent variability of the cement-making process. The NO emissions averaged about 8 lb NO₂/ton of clinker and varied approximately 30 percent during the as-found test series. Lowering kiln exit oxygen from 1.8 percent to 0.7 percent reduced NO by 15-20 percent. Three days of nitrogen injection tests for primary air vitiation were also performed at the test site. Although the testing demonstrated that nitrogen injection will reduce NO, the extent of reduction is extremely variable and is based on the operations and kiln feed at the time. NO mass emissions did decrease 20 to 30 percent, based on altering the burning zone temperature profile (2550°F to 2490°F) and lowering the primary air O₂ from 21 to 13 percent while maintaining a constant kiln exit oxygen of 1.5 percent. No deterioration of clinker quality was observed. For long-term operation, flue gas recirculation would be a more cost-effective means of achieving primary air vitiation.

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ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Robert E. Hall, initial Project Officer, whose direction and evaluation were an important contribution to the program. The efforts of Nancie Parker and Adam Frohoff are also appreciated for the data reduction phase of the program.

Acknowledgment is also made of the contributions of the environmental, engineering, operating and maintenance personnel of the plant at which the test kiln was located. Without their willing cooperation, the program could not have been conducted.

Limitations on Application of Data Reported

The pollutant emission data cited in this report pertain to one specific classification of cement kilns; i.e., long dry kilns. These data should not be used to estimate mean emissions from long dry kilns or other types of kiln. The test data should not be used to predict emission reduction potentials of combustion modifications until the modifications have actually been carried out on the different types.

SECTION 1.0

INTRODUCTION AND SUMMARY

1.1 OBJECTIVES AND SCOPE

KVB has been funded by the U.S. Environmental Protection Agency to conduct research for emission reduction from industrial processes. One phase of this research effort concerns NO_x reduction from cement kilns. Initially, combustion modifications were tested on a laboratory-scale simulated cement kiln (Ref. 1); then tested on a subscale cement kiln (Ref. 2). The modifications were evaluated for the emission reduction potential as well as the feasibility of these modifications for adaptation on a pilot-scale cement kiln.

Of the combustion modifications evaluated in the previous studies, vitiation of the primary air with inert gas was considered the best alternative for NO_x reduction on a pilot-scale kiln. A specific objective of this program was to examine the alternatives available for primary air vitiation on a pilot-scale cement kiln and recommend the best approach for proving the method as a viable NO_x reduction technique. Based on engineering analysis and cost tradeoffs of the various sources of inert gas systems, nitrogen injection of the primary air stream was the best alternative. Another specific objective of the program was to implement this combustion modification on the kiln and run demonstration "proof of principle" tests. These "proof of principle" tests would consist of approximately three days of nitrogen injection tests to determine the effectiveness of primary air vitiation on a pilot-scale kiln. The modification would be studied for NO_x reduction from a reference baseline and impact on production clinker quality.

1.2 REVIEW OF PREVIOUS WORK

The present program is a follow-on study intended to build upon the results of the program reported in Reference 1. The objective of the earlier effort was to determine the effect of burner parameters on near-flame NO_x levels for both natural gas and coal fuels. This laboratory effort determined that combustion air preheat, fuel injection velocity, and oxygen content of the primary combustion air stream have first-order effects on NO_x levels. These parameters were then selected for implementation on the subscale kiln. Of these three combustion modifications, the effect of carrier (primary) air oxygen concentration on NO_x emissions was most significant.

One of the major objectives of the subscale kiln test program was to determine the effect of carrier (primary) air O_2 concentration on NO_x emissions under real process conditions. The carrier air circuit of the test facility was plumbed so that an inert gas could be injected into the air

stream upstream of the orifice which measured the flow in the circuit. Downstream of the measurement orifice, a sample port was installed for measuring the O_2 concentration of the carrier air.

A series of tests were conducted with gaseous nitrogen injected into the carrier air stream. The effect of carrier air oxygen content on NO_x emissions is shown in Figure 1 for the kiln operating at an overall O_2 level of 4 percent. These data show the strong influence in NO_x emissions as a function of carrier gas oxygen concentration. NO_x emissions were reduced 37 percent by lowering the carrier gas oxygen to 12.5 percent. While NO_x reduction was significant, the subscale clinker quality was not comparable to production clinker. Primary air vitiation did not seem to affect clinker quality substantially from the baseline condition. Acceptable production clinker is approximately 0.5 to 1.5 percent free lime. Also shown in the figure are the results of the combustion laboratory tests which were corroborated by the subscale test results.

Based on these test results, KVB felt that dilution of the primary air stream with an inert gas offered the highest probability of NO_x reduction by combustion modification on a pilot-scale kiln.

1.3 PRESENT APPROACH

KVB contacted a California cement company regarding the possibility of modifying a pilot-scale, coal-fired, grey-cement kiln for carrier gas dilution. The cement company was cooperative for such a test program since emission limit goals of 3.1 lb NO_x /ton clinker are being considered by the local air quality management district. Data with inert gas injection would be useful input for the decision-making process as to whether the emission limit is feasible or not.

A number of tasks were undertaken by KVB as part of the current EPA contract. KVB engineers worked with the cement company plant staff to design and install a least-cost inert gas injection system as a first cut attempt to determine if this concept shows promise. The least-cost inert gas injection system for "proof of principle" tests was a nitrogen injection system. Prior to nitrogen injection testing, several days of as-found emissions and operations data were collected. The as-found test results were reviewed by KVB and the cement plant personnel and compared to previous data obtained by the cement company. The interrelationships between operations and emissions data on an as-found basis were assessed to better understand the variability of gaseous emissions. Due to the inherent variability of the cement process, it was important to establish operating conditions which would not obscure the effect of inert gas injection on NO emissions. Also, a reference baseline test with comparable operating conditions to the nitrogen injection test would be needed to clarify any differences in NO emissions.

Three days of nitrogen injection tests were performed at the test site. The results were compared to subscale test results to determine whether the inert gas injection system, in fact, appears to offer promise of meeting the cement company's emission limits goal.

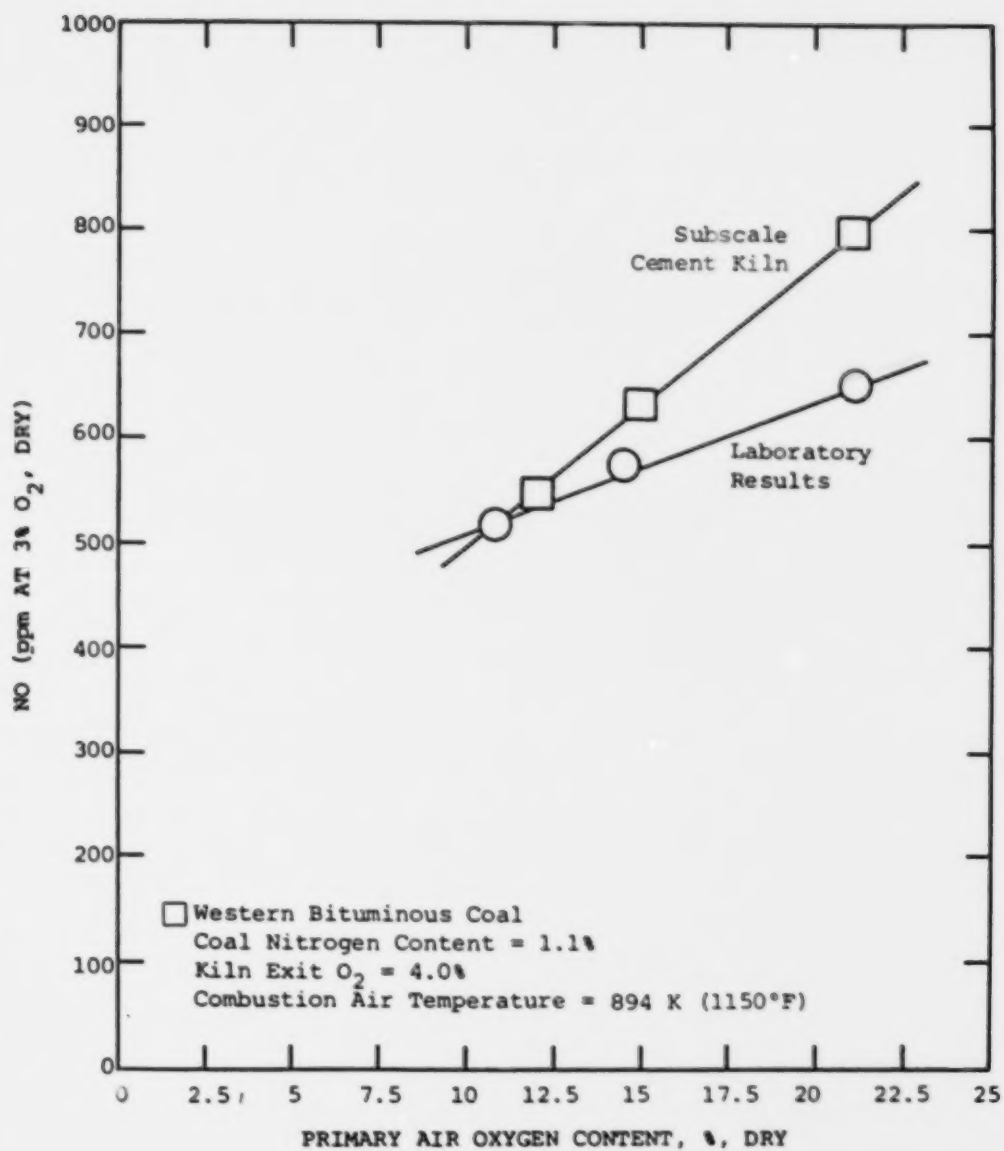


Figure 1. Effect of Primary Air Oxygen Content on NO_x Emissions

It should be noted that the NO_x was measured on a dry basis, thus all emissions data and reductions are reported as NO.

1.4 CONCLUSIONS

- The objectives of the program were satisfied regarding the evaluation of primary air vitiation on a full-scale kiln.
- The cement kiln tested had inherent substantial variability in many process parameters which affect NO emissions. This variability considerably complicated the investigation of the applicability of combustion modifications.
- Stabilizing the process must be an essential part of any attempt to control NO emissions by combustion or process modifications.
- The proof of principle testing demonstrated that nitrogen injection will reduce NO in a full-scale kiln. The extent of reduction appears to be not as significant as that observed in the laboratory and subscale tests.
- NO was reduced during short-term nitrogen injection tests, with reductions of the order of 25 to 30 percent. Because of interacting variables, it was not possible to clearly isolate the effect of nitrogen injection.
- Statistical analysis of the data from the nitrogen injection test series shows a 16 to 76 ppm decrease in volumetric NO emissions per one percentage point decrease in mill outlet oxygen. The actual decrease depends on what is held constant by the model.
- Injection of nitrogen produced a longer, cooler flame, an effect that would require much further investigation, over a longer time, before full-time implementation would be possible.
- Clinker quality remained within the range of normal variability for the kiln tested with no apparent deterioration during low excess air and nitrogen injection tests.
- The test program met the objective of evaluating the effect of combustion modification on product quality, but only on a short-term basis. Longer term tests with improved process stability are required.
- A specific NO reduction potential of primary air vitiation on a volumetric or mass emissions basis cannot be concluded from the proof-of-principle nitrogen injection test series conducted.

- As-found emissions (17 days of data, 89.75 hours) were approximately 8 pounds NO as NO₂ per ton of clinker compared to the previously established baseline of 5.65 pounds NO as NO₂ per ton of clinker (8 hours of data).
- Forty-nine consecutive hours of as-found data were analyzed for 3-hour and 24-hour rolling averages. The 3-hour rolling averages ranged from 4.62 to 10.04 pounds NO (as NO₂) per ton of clinker and the 24-hour rolling averages ranged from 6.69 to 8.42 pounds NO (as NO₂) per ton of clinker.
- Lowered excess air (LEA) decreased NO volumetric and mass emissions by approximately 15 to 20 percent. The percent reduction was established from a reference baseline of 1050 ppm (corrected to 3 percent O₂) and a kiln exit oxygen of 1.82 percent. The NO volumetric emissions were lowered to 880 ppm (corrected to 3 percent O₂) with a kiln exit oxygen of 0.7 percent. The average calculated pounds NO as NO₂ per ton of clinker was 8.07 at reference baseline and 7.02 at low excess air conditions; the resultant reduction was 13.0 percent. The average burning zone temperature, as measured by an optical pyrometer, was 2477°F at reference baseline conditions and 2460°F at LEA conditions. The effect of kiln feed burnability factor on NO emissions was not included in this analysis.
- The air quality management district's proposed mass emissions ceiling of 3.1 pounds NO (as NO₂) per ton of clinker is not feasible based on the percent reduction achieved with low excess air or nitrogen injection plus low excess air under the material temperatures observed.
- For long-term operation, flue gas recirculation would be a more cost-effective means of achieving primary air vitiation.

SECTION 2.0

ALTERNATIVES FOR PRIMARY AIR DILUTION

Four alternatives were considered for partial inerting of the primary air stream. These alternatives were:

- . 200 hp boiler
- . 600 hp boiler
- . Flue gas recirculation
- . N₂ injection

Alternatives were analyzed for initial and operating costs, operability and flexibility. The initial and operating costs are approximations not quotes.

2.1 200 HP BOILER

An existing 200 hp boiler from the KVB laboratory, used for the CO gas combustion tests on this contract, would supply enough flue gas to an ambient air stream to provide a carrier gas O₂ level of approximately 17 percent. The temperature of the mixture would be 544 K (520°F) assuming that all of the flue gas is pulled from the first pass of the boiler. The NO_x reduction with 17 percent O₂ in the carrier gas was judged not significant enough for a "proof of principle" test. For this reason, the 200 hp boiler was not considered.

2.2 600 HP BOILER

Table 1 lists the detailed costs for a 600 hp system. The 600 hp boilers would provide enough flue gas which when mixed with ambient air would provide an O₂ level of approximately 10 percent. The flue gas would be pulled out of one of the boiler passes depending on the gas temperature needed to maintain a temperature of 533 K (500°F) in the primary air/flue gas stream. The system would have more flexibility for testing a wide range of O₂ concentrations with far lower operating costs than the N₂ injection system. However, the initial costs for equipment and labor are quite high and are impractical for consideration on a short-term (1 to 2 day) test program. The major operating costs would be fuel costs. Gas costs are listed in the table but it is anticipated that No. 2 oil may be a more attractive option (less setup and installation costs). Table 2 summarizes the advantages and disadvantages of the 600 hp boiler.

TABLE 1. ESTIMATED COSTS FOR 600 HP BOILER
10 DAYS OF OPERATION

Description	Quantity/Rate	Fixed Costs	Operating Costs (gas)
Boiler Rental	\$8,000-9,000 (1 month)	\$ 9,000	
Modification/ Restoration	\$3,000-5,000	\$ 5,000	
Transportation	\$500-2,000	\$ 2,000	
Fuel Costs	25.1 x 10 ⁶ Btu/hr x \$5.75/10 ⁶ Btu x 80 hrs.		\$ 9,600
Water Costs (100% makeup + Water Softener/ Chemicals)			\$ 2,000
Fan Electrical Costs			\$ 360
Gas Hookups, gas pipeline regulator, etc.		\$ 5,000	
Control system (Motorized Butterfly Valves Instrumentation, Ducting, Inc.)		\$20,000	
Contingency		<u>\$11,160</u>	<u> </u>
	Subtotals	\$52,160	\$12,560
	Total	\$64,720	

TABLE 2. COSTS/ADVANTAGES/DISADVANTAGES OF 600 HP BOILER

Estimated Costs (10 Days)

- . \$65,000

Advantages

- . 10 percent O₂
- . More test flexibility

Disadvantages

- . More controls and instrumentation needed (more complex)
 - . Attendant needed full-time
 - . Outage probability greater with boiler than N₂ or FGR system
 - . High fuel costs to operate boiler
 - . Unrealistic setup for permanent installation
 - . Adds moisture to coal/primary air stream
-
-

2.3 FLUE GAS RECIRCULATION

Of the four alternatives considered, flue gas recirculation would be the most permanent system. Flue gas would replace all of the primary air. Flue gas would be extracted downstream of a multiclone, pulled through a smaller cyclone by an I.D. fan and ducted to the coal mill inlet. The long distance that the flue gas must travel (240 to 270 m, 800 to 900 feet) and uninsulated ducting results in essentially ambient flue gas temperature at the mill inlet. Since the carrier stream must be 505 to 533 K (450 to 500°F), duct burners or some form of reheating would be needed to raise the flue gas temperature. The capital costs for the system are on the order of \$125,000 but the operating costs are very low. Table 3 itemizes the costs associated with the flue gas recirculation system. The significant operating cost is fan electrical cost. Table 4 summarizes the estimated cost, advantages and disadvantages of the flue gas recirculation system.

2.4 NITROGEN INJECTION

Nitrogen injection of the primary air stream was the best alternative for a very short term test. Table 5 lists the advantages and disadvantages of nitrogen injection. A liquid nitrogen pumper with nitrogen vaporizer would be supplied by a local service. The gaseous nitrogen can be supplied at the flow

TABLE 3. ESTIMATED COSTS FOR FGR SYSTEM
Installed Costs and Operating Costs (10 days)

Description	Quantity	Installed Costs	Operating Costs
16" Schedule 20 pipe	900'	\$ 36,324	
Buttwelds	20	2,020	
Bracket Supports (50' Span)	25	5,000	
Expansion Joint	3	3,000	
Butterfly Valves w/Motor	3	2,700	
High Temp. Suction Fan and Motor	1	10,000	\$1,000
Booster Fan & Motor	1	7,000	
Starter Motor	2	6,000	
Fan Support	2	2,000	
Cyclone 8000 scfm	1	4,200	
Dusthopper	1	700	
Cyclone Stand	1	6,340	
Dust Removal	1	-	
Control System	1	10,000	
Duct Burners & Flanges, 1.5 MMBtu each	3	5,500	
Gas Pipe 300'	300'	<u>1,800</u>	
		\$102,674	
Contingency costs (20%)		<u>\$ 20,534</u>	
	Subtotals	\$123,208	\$1,000
	Total	\$125,000	

TABLE 4. COST/ADVANTAGES/DISADVANTAGES OF FLUE GAS RECIRCULATION

Estimated Cost

- . \$125,000

Advantages

- . Can achieve very low O₂ concentration (less than 10 percent)
- . Permanent installation (if desired)
- . Low operating costs

Disadvantages

- . Duct burners needed to heat flue gas back to 500°F
 - . High installation costs
-
-

TABLE 5. ADVANTAGES/DISADVANTAGES OF N₂ INJECTION SYSTEM

Advantage

- . Can achieve low O₂ concentration (~10 percent) in primary air/N₂ stream
- . Easier setup, minimal controls
- . No duct burners needed to heat air/N₂ mixture to 500°F
- . Easier system to operate and control
- . No moisture added by N₂ system

Disadvantages

- . Unrealistic setup for a permanent installation
 - . Very high operating costs
-
-

rates needed to achieve an overall primary air/N₂ stream O₂ down to 15 percent. Also, the gaseous nitrogen can be supplied at temperatures up to 590 K (600°F). This is highly desirable for maintaining the carrier stream at 533 K (500°F) at the coal mill inlet. The nitrogen injection system has a disadvantage of high operating costs (\$1.35/10² ft³) but is a very good system in terms of easy installation, operability, and low capital investment costs.

The extent of the test was two to three days to determine the effectiveness of NO_x reduction with primary air dilution and attendant effect on production clinker quality. Based on successful N₂ injection tests, a decision would be made to proceed with more testing with a temporary system (i.e., 600 hp boiler or N₂ injection) or with a permanent system (flue gas recirculation).

SECTION 3.0

TEST EQUIPMENT DESCRIPTION

This section presents information on the kiln system design and operation, a description of the nitrogen injection system and a discussion of emissions sampling equipment for monitoring mill outlet and kiln exit conditions. Also, a brief discussion of feed, clinker and fuel sample collection and analysis is included.

3.1 KILN SYSTEM DESIGN AND OPERATION

Figure 2 is a schematic of the dry process cement kiln system showing all of the major components. The discussion of the kiln design, raw feed system, kiln process description, fuel delivery system and kiln system controls is presented below.

3.1.1 Kiln Design

The test facility for these combustion modification tests is a long dry rotary cement kiln located at a California cement plant. This six support rotary kiln is 149 m (490 ft) long and 4.1 m (13.5 ft) inside diameter. A schematic of the rotary kiln and the dimensions of the kiln is shown in Figure 3. Two 150 hp motors are required to drive the kiln. The slope of the kiln is 7/16-inch per foot. Maximum kiln speed is 1.33 rpm (90 rph). Kiln production rate is rated at 45 tons per hour of clinker. The thermal input rate is approximately 70.3 MW (240×10^6 Btu/hr).

3.1.2 Kiln Feed

Two feed types were burned in the kiln during the test program. A Type II raw feed was primarily burned. Type II raw feed consists of mix rock, silica, shale clay and iron ore. The proportions of these components are monitored on a consistent basis. The primary differences between Type II and III raw feeds is replacement of a portion of the shale component with aluminum oxides and minimal use of iron ore. Type III raw feed has very little iron ore which tends to make the feed "harder burning." Iron has a favorable influence on the reaction between lime and silica in the formation of silicate cement products.

All of the raw mix feed components needed to make a specific type of cement are interground in ball mills and stored at holding areas. The finely ground feed is stored in one of two homogenizing silos and then transported to one of four kiln feed storage silos. The feed is conveyed by one of two air slide chutes to the kiln feed bin and then conveyed by a constant head screw feeder to the kiln feed box. Typically, 17 feeder revolutions will provide enough feed (1.65 tons raw mix) for 1 ton of clinker. For a particular feed

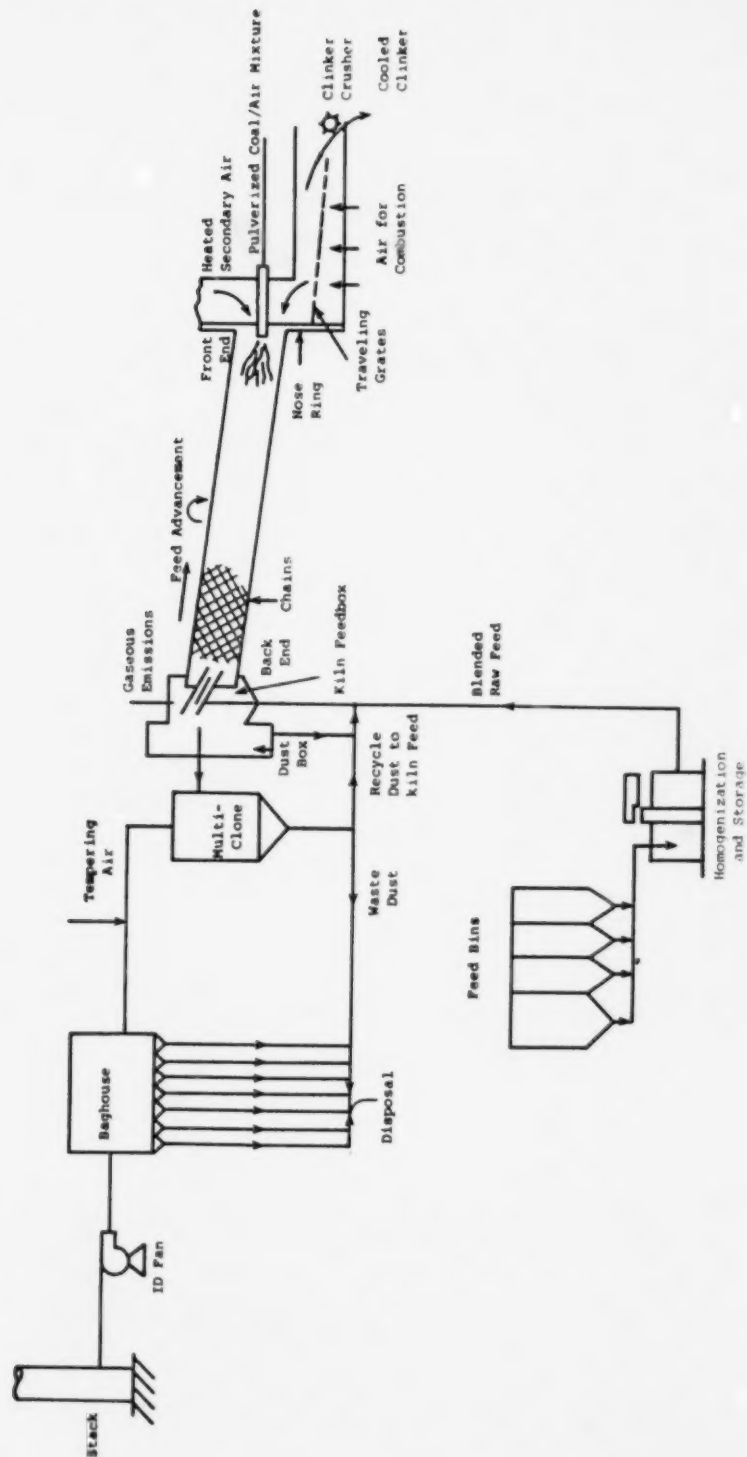
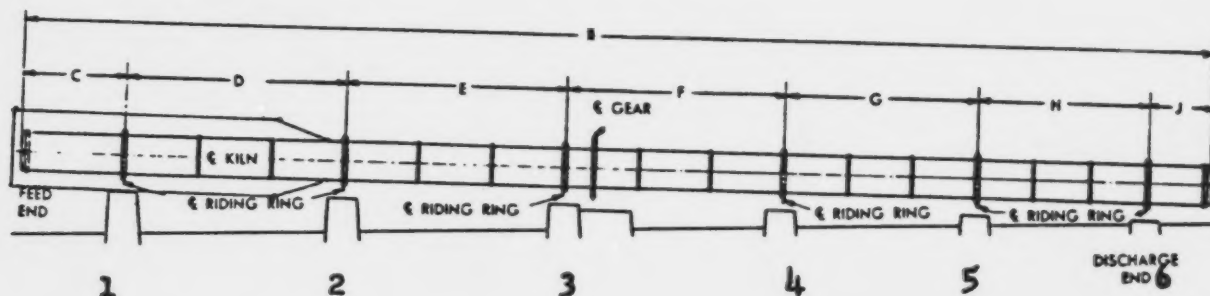
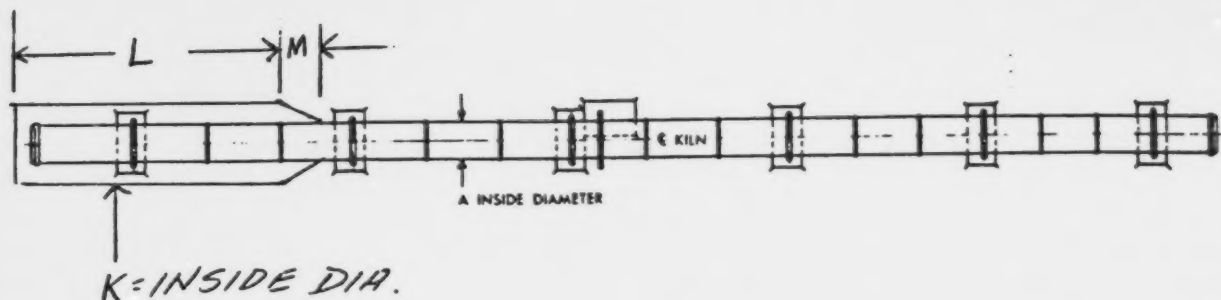


Figure 2. Schematic of Dry Process Cement Kiln System

ROTARY KILN

Six Support



Slope of Kiln..... $7/16''$ Per Ft
 Maximum Kiln Speed..... 1.33 Rpm
 Motor Size Required..... $7HP = 150$ Hp

DIMENSION

A... $13'$	F... $92'$
B... $490'$	G... $94'$
C... $33'$	H... $81.5'$
D... $89.5'$	J... $12'$
E... $88'$	K $15'$
	L $80'$
	M $27'$

Figure 3. Rotary Kiln Schematic and Kiln Dimensions

type, the kiln feeder speed/kiln speed ratio is a constant. The control kiln feeder ratio (kiln feeder speed divided by kiln speed) is kept at approximately 0.205 for the Type II feed and 0.190 for the Type III feed.

3.1.3 Fuel Delivery System

A Southern Utah bituminous coal is normally burned. Figure 4 is a drawing which schematically shows the coal mill, the air ducts and coal feeder pipes. The kiln is direct fired from a Raymond Model 573 pulverizer rated at 7 tons per hour. A booster fan has been added to increase fuel delivery to 10 tons per hour, uncorrected for moisture loss. The coal drying in the mill decreases the coal moisture from seven percent moisture to approximately two percent moisture. Thus, the coal delivery to the burner is approximately 9.5 tons/hr maximum. The pulverized coal is air conveyed to the kiln from the coal mill located near the burner end of the kiln. Hot air is withdrawn from the kiln hood through a cyclone for dust dropout then mixed with tempering air to provide coal mill transport air. The temperature of the primary air entering the coal mill is maintained between 505 to 560 K (450 to 550°F). The mill outlet temperature and flow rate (nominally 10,000 acfm at 175°F) are controlled automatically by the modulation of the hot air and tempering air dampers. Approximately 20 percent of the total combustion air is introduced through the coal pipe as primary air. Gas is used for kiln startup and in situations where the burning zone must be reheated quickly. Oil is the primary backup fuel.

3.1.4 Kiln Process Description

Cement clinker in a long dry kiln is produced in the calcination, clinkerization and clinker cooler zones. The raw feed material is discharged as a dry pulverized powder into the upper end of the kiln through a feed pipe. The feed passes through a chain section which heats the feed rapidly as the result of the heat exchange process between the hot flue gas and the chains. The calcination process (dissociation of carbon dioxide from the carbonates of calcium and magnesium) theoretically occurs in the middle third of the kiln. Complete calcination of the feed is needed for good production clinker. The calcined feed is then clinkerized in the burning zone. Clinkerizing is the partial liquefying of the clinker constituents and the formation of the four principal cement products: dicalcium silicate (C_2S), tricalcium silicate (C_3S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF). The formation of these cement constituents (calcium combined with silica or alumina) is analyzed with the amount of uncombined "free" lime (0.5 to 1.5 percent regarded as good) as part of the final product analysis.

As the calcined feed proceeds towards the lower end of the kiln (burner end), the high temperatures resulting from the combustion of the pulverized coal heat the feed to its sintering temperature.

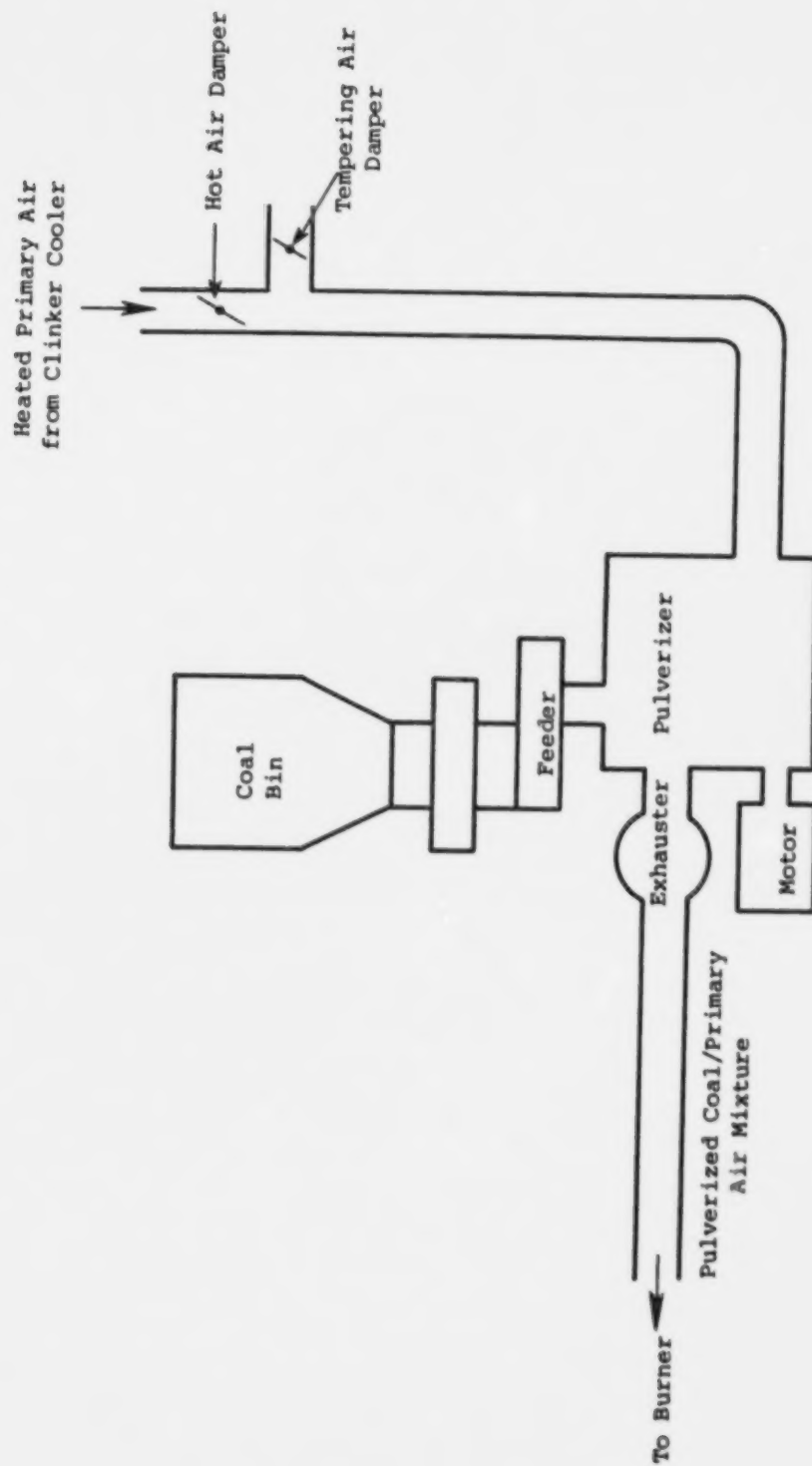


Figure 4. Schematic of coal mill, air ducts, and coal feeder pipes.

3.1.5 Kiln System Controls

The kiln system is instrumented for emissions data along with temperatures and pressures and controls for the coal mill system, clinker cooler box, kiln itself and downstream (i.e., multiclone and baghouse). Feed input (fuel and raw material basis) and clinker product output are also monitored. Table 6 details the kiln system controls used for monitoring kiln system operation.

3.2 NITROGEN INJECTION OPERATIONAL SETUP

Gaseous nitrogen was injected downstream of the stack damper "tee" where the hot air and tempering air dampers are located. The flow and instrumentation diagram (Figure 5) shows that a cryogenic pump pushes liquid N_2 to a direct-fired heat exchanger where the nitrogen vaporizes and flows through a metering valve, a shut off gate valve and diffuses into a sixteen inch duct. The cryogenic pump is a positive displacement, variable speed pump. The pump can deliver a fairly steady nitrogen flow rate over a wide range of discharge pressures. Temperature, pressure and flow rate of the nitrogen are continuously monitored on the truck-mounted pumper facility supplied by the nitrogen vendor.

The key control variables for the nitrogen injection testing were mill outlet O_2 , mill outlet temperature and mill carrier gas flow rate. Mill outlet O_2 was monitored by KVB personnel. The mill outlet O_2 adjustments were made manually in conjunction with the operations personnel of the host site and the N_2 truck operator. The operator was advised to raise or lower N_2 flow rate based on the desired mill outlet O_2 . Flame stability was monitored with the changes in mill outlet O_2 .

Table 7 shows the theoretical amount of gaseous nitrogen needed to decrease the primary air oxygen to a desired level at 500°F. The measured oxygen levels in the primary air were compared against the calculated O_2 from the nitrogen injection rate. For the primary air oxygen concentrations considered, a minimum nitrogen delivery temperature of 450°F was expected.

Mill outlet temperature was already measured in the control room and maintained automatically by modulation of the hot air and tempering air dampers. The nitrogen injected into the primary air duct was maintained at approximately the same temperature as the air. The transition pieces from the pumper to the 32" duct did not need to be insulated to compensate for expected temperature losses. A thermocouple was situated in the 16" duct to monitor the gaseous nitrogen temperature entering the primary air duct.

Mill outlet flow rate was maintained by modulation of the hot air and tempering air dampers when gaseous nitrogen was injected into the carrier gas stream. Proper flow rates are needed to prevent pulverized coal settling in the burner line.

TABLE 6. HOST SITE CONTROL ROOM INFORMATION

Kiln	Downstream of Kiln	Kiln Back End Emissions	Cooler	Coal Mill
Speed, rph	Baghouse Inlet Temp, °F	O ₂ , %	Air temp, °F	Motor Amps
Feeder Speed, rpm	Baghouse ΔP, "H ₂ O	CO, ppm	Speed, rpm	Inlet temp., °F
End Housing Pressure, "H ₂ O	Multiclone Inlet Temp, °F	CO ₂ , %	Undergrate Pressure, "H ₂ O	Outlet Temp., °F
Shell Temp., °F	Kiln ID Fan Damper Position %	NO _x , ppm	Undergrate Temp., °F	Inlet Pressure, "H ₂ O
Load, amps			Clinker Belt scale	Outlet Pressure, "H ₂ O
Hood Pressure, "H ₂ O				Feed Rate, rph
Material temp.* °F				Cyclone Temporing Air, °F

*Although identified as material temperature in the control room, the measurement with the optical pyrometer fixed on a specific spot in the kiln is actually burning zone temperature.

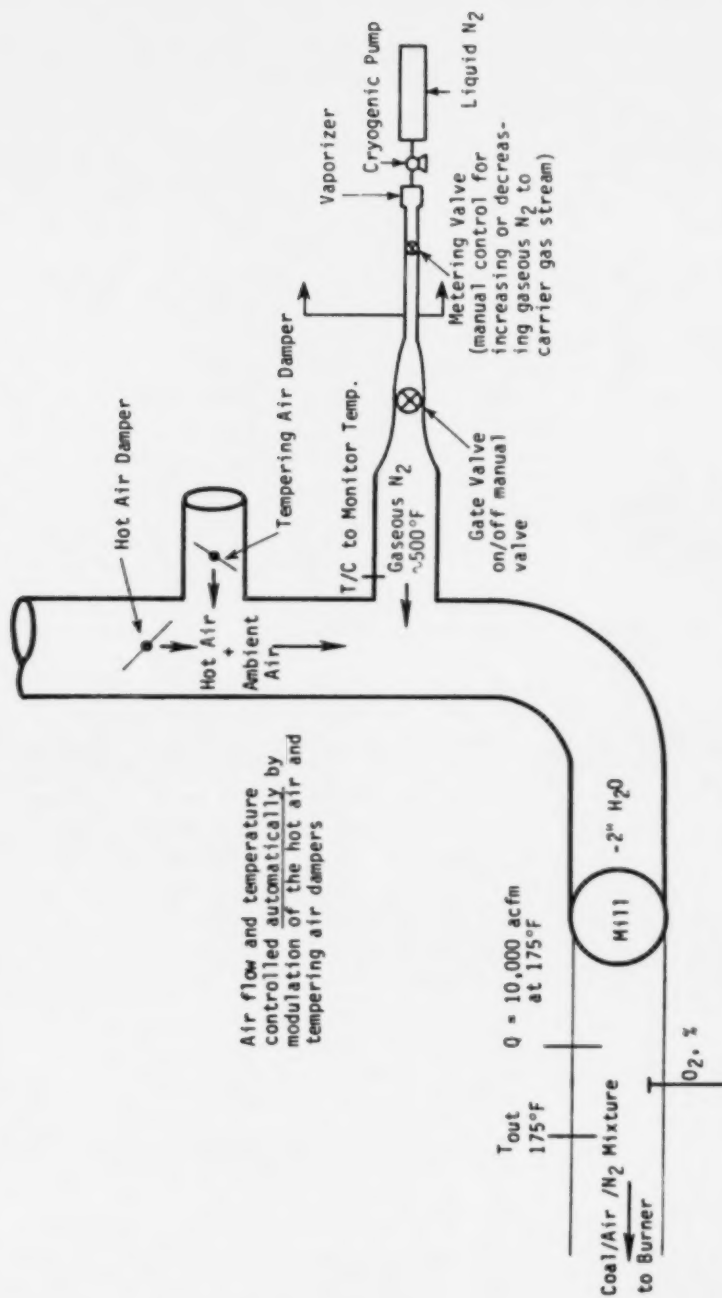


Figure 5. Flow and Controls Schematic for Coal Mill Carrier Air

TABLE 7. NITROGEN FLOW RATES FOR DILUTING CARRIER GAS

Carrier Gas % O ₂	Primary Air (acfm)	Gas N ₂ (acfm)	Gas N ₂ (scfm)
21	15,297	0	0
20	14,569	728	364
19	13,840	1,457	729
18	13,112	2,185	1,093
17	12,383	2,914	1,457
16	11,655	3,642	1,821
15	10,926	4,371	2,186
14	10,198	5,099	2,550
13	9,470	5,827	2,914
12	8,741	6,556	3,278

Mill Outlet Conditions 10,000 acfm at 175°F

Mill Inlet Conditions 15,297 acfm (38,000 lb/hr) air at 500°F

3.3 EMISSIONS SAMPLING EQUIPMENT

Gaseous emission measurements were made using analytical instruments and equipment contained in a government-furnished mobile instrumentation laboratory. N_2O is measured by G/C.

3.3.1 Gaseous Emissions Sampling System

The laboratory was equipped with analytical instruments to continuously measure concentrations of NO , CO , CO_2 , and O_2 . The sample gas is delivered to the analyzers at the proper condition and flow rate through the sampling and conditioning system described below. Appendix A describes the analytical instrumentation and the details of the sampling system. Also, a flow schematic and description of the flue gas sampling and analyzing system is presented in detail in Appendix A. Briefly, the sampling system used pumps to continuously draw flue gas from the heater into the laboratory. A high-capacity heated positive displacement diaphragm pump was used to draw a high volume of flue gas into the analyzers thereby providing adequate system response.

For the as-found, low excess air and nitrogen injection test series, NO was measured. Measurement of total NO_x ($NO + NO_2$) requires a heated sample line and involves a differential measurement of NO and total NO_x , the difference being NO_2 . Conditions in the pilot-scale kiln were not sufficiently steady to allow accurate differential determination of NO_2 . Thus, the added complexity of a heated line was not deemed necessary and NO_2 was not measured.

A portion of the sample pump discharge was also sent through a refrigerated condenser [to reduce the dew point to 275 K (35°F)], through a large rotameter with flow control valve, and then to the O_2 , NO , CO , and CO_2 instrumentation. Flow to each individual analyzer was measured and controlled with smaller rotameters and flow control valves. Excess sample was vented outside the laboratory.

3.3.2 N_2O Measurement

Samples are collected by expanding the stack gases into evacuated 2-liter Pyrex flasks fitted with grease-free O-ring stopcocks. Prior to sampling, the flasks were baked for four hours at 200°C under high vacuum. The samples are analyzed by gas chromatographic measurement of the N_2O/CO_2 or N_2O/O_2 ratio.

3.3.3 Recording Instrumentation

An On-line Emissions Monitor Program was written for the Apple II Plus 48K computer to provide automatic digital data acquisition for real time monitoring of emissions data. The data logger was programmed to scan every five seconds and print the gaseous emissions data every one, three, or five minutes. The program provides a continuous visual display of time plots for

two gaseous species (e.g., NO, O₂) and records the data printed out on magnetic disk. Strip chart recorders are used to verify the data recorded on magnetic disk and fill in any gaps from the data logger, should they occur.

3.3.4 Primary Combustion Air O₂ Monitor

The sampling for oxygen levels in the primary air conveying the coal to the burner during the nitrogen injection tests was performed using a portable Teledyne Model 320A oxygen analyzer. The sample port for oxygen measurement was located in the 16-inch diameter burnerline approximately 50 ft from the burner front. During the N₂ tests, carrier gas O₂ was monitored every minute to two minutes. The portable meter was calibrated on the 0 to 25 percent O₂ scale by running ambient air through the analyzer and then adjusting the reading for 21 percent. The calibration with ambient air was checked at least twice each hour.

At least once a day, a leak check was performed on the sampling system and the portable analyzer. This was accomplished by injecting pure nitrogen into a gas loop which were attached to the analyzer and then running the portable Teledyne for five minutes and determining whether the O₂ readout rose above the baseline N₂/zero level. Quick checks were made of any leaks in the system by plugging the sampling line from the probe outlet to the instrument.

The calibration standard was ambient air at 21 percent. The analyzer was operated on the 0 to 25 percent O₂ range and was cross-checked versus certified bottles of 10.5 percent O₂ on the 0 to 25 percent O₂ range. The difference between the meter reading when calibrated on air and when calibrated on certified 10 percent O₂ was logged and the variance of the calibration was then calculated.

3.4 FEED, FUEL, AND CLINKER SAMPLE COLLECTION AND ANALYSIS

Raw feed samples were drawn from one of two air slide chutes which feeds the kiln bin. These samples did not include recycled dust drawn from the multiclone. A combined feed sample (raw feed plus recycled multiclone dust) was taken from the constant head feeder screw just upstream of the kiln feed end.

Clinker samples were collected from one of two locations. If the clinker weigh belt scale for each kiln was on line, the cooled sample would be collected downstream at the weigh belt scale. The time delay between the kiln feed discharge end and the weigh belt scale is approximately 25 minutes. This time differential was used to correlate emissions data to free lime analysis. The other sampling location was at the kiln discharge end. This location was used if the clinker conveyor belt and scale were off-line. The hot clinker was collected in a long handle collection cup prior to landing on the clinker cooler grate. Clinker samples were analyzed by both KVB and the host site (Ref. 3). The analysis methodology used by both KVB and the host site is included in Appendix B.

Coal samples were collected from the burner line pipe approximately 50 feet from the burner. The samples were analyzed for proximate and ultimate analysis by an independent testing laboratory. A particle size distribution was also performed on one of the fuel samples.

SECTION 4.0

ANALYTICAL METHODS AND DATA PRESENTATION

The purpose of this section is to briefly describe the statistical methods and analytical methods used to present the data reported in Sections 5, 6 and 7. These methods are important for interpreting the variability of kiln operation and variability of gaseous emissions on a volumetric basis and a mass basis. Section 4.1 describes the statistical methods used in the report. Section 4.2 details the methods for determining clinker rate. Section 4.3 details the methods followed for calculating the pounds NO (as NO₂) per ton of clinker. Section 4.4 discusses the uncertainties of calculating pounds NO₂ per ton clinker with each method.

4.1 DATA REPORTING

Daily kiln exit gaseous emissions normally analyzed were NO, CO, CO₂, and O₂. The O₂, CO₂ and CO data are reported on a dry volume basis and the NO data are reported on a dry volume basis corrected to 3 percent O₂. The dry stack gas data are statistically analyzed for the arithmetic mean, sample standard deviation, coefficient of variation and 95 percent confidence level. The coefficient of variation* is used as a quantitative measure of kiln operation variability. A low coefficient of variation (10 to 20 percent) for NO emissions over a particular time interval would indicate fairly steady kiln operation. The 95 percent confidence interval is also used to quantitatively describe the range of data about the mean.

Gaseous emissions of carbon monoxide and nitric oxide are also reported on a weight per thermal input basis (nanograms per joule). These mass emissions data are reported for the arithmetic mean, sample standard deviation and the 95 percent confidence interval.

The volumetric NO concentration is converted to a pounds per ton of clinker basis and reported as NO₂. The pounds NO₂ per ton of clinker is based on the fuel firing rate (10⁶ Btu per ton of clinker) and the pollutant emission rate based on a weight per thermal input, reported as pounds NO₂ per 10⁶ Btu. The fuel firing rate depends on the clinker rate determination. Section 4.2 describes the five methods available for calculating the clinker rate. Section 4.3 details the three methodologies used to determine the pounds NO₂ per ton of clinker. The percent deviation of the mass emissions factor between the methods is reported in the as-found results, nitrogen injection data and low excess air tests.

*Coefficient of Variation = $\frac{\text{Standard deviation}}{\text{mean}} \times 100\%$

Both single linear regression analyses and multiple linear regression analyses are performed on the reference baseline and nitrogen injection data. The equations generated for the dependent variable (NO as NO₂ ng/J and NO₂ lbs/ton clinker) are then used to compare reduction potential under similar operating conditions. Much of the NO as NO₂ ng/J variation are due to kiln exit O₂ change and burning zone temperature change.

4.2 CLINKER RATE DETERMINATION

Five methods are available for determining clinker rate (tons/hr). Four methods are based on plant instrumentation and one method is based on the coal analysis, raw feed ignition loss and gaseous emissions. The plant measurements used for clinker rate are the following:

- Clinker Weigh Belt Scale
- Kiln Feeder Speed (strip chart)
- Kiln Feeder Revs Counter
- Kiln Speed

The clinker weigh belt scale integrator is a direct measure of clinker throughput per unit time. This instrument, however, did not often provide the clinker throughput for the test kiln. The test kiln clinker belt was sometimes off-line for repair. Thus, clinker from the test kiln is weighed cumulatively with clinker produced from the sister kiln. Conversely, if the weigh belt scale for the sister kiln was off-line, all clinker (test kiln plus the sister kiln) were measured on the test kiln's weigh belt scale. The accuracy of the clinker weigh belt scale is ± 5 percent.

Calculation of clinker rate from kiln feeder speed is based on an average value of 17 feeder revs/per ton clinker. Since feeder revs is tied to kiln speed, a higher number of feeder revs per ton of clinker (18 to 19) is expected at higher kiln speeds (80 to 90 rph) and a low number of feeder revs per ton of clinker (15 to 16) is expected at lower kiln speeds (50 to 60 rph). Kiln feeder speed is continuously time traced on strip charts over the range of kiln speeds encountered.

The kiln feeder revs counter reading was recorded periodically (one minute or five minute intervals) through the course of a testing day to see how kiln feeder speed calculated from the revs counter compares with the strip chart kiln feeder speed. A comparison of the kiln feeder speed readings from the strip chart and kiln feeder speed calculated from the kiln feeder revolution counter over a five minute time interval showed that the kiln feeder speed readings are consistently higher (Section 6.1 and 6.2, November 15th and 17th). For the as-found data, 28 data points are available from which the average percentage difference between the clinker rate determined from kiln feeder speed strip chart and kiln feeder speed (revs counter) was 6.19.

Kiln speed strip chart can be used to determine kiln feeder speed and in turn clinker rate. The kiln feeder ratio (kiln feeder speed divided by kiln

speed) is maintained as a constant for any one particular feed type. For example, the feeder ratio is 0.205 for the Type II feed. A time weighted average kiln feeder speed can be derived from the kiln speed strip chart and constant. Since the kiln feeder speed strip chart was always readily available, use of kiln speed strip chart for clinker rate determination was not needed.

While the above discussion is restricted to clinker rate as determined by plant instrumentation, a clinker rate can also be calculated from a formula for MMBtu per ton clinker based on gaseous emissions data (CO_2 , O_2), heating value, ultimate analysis, and ignition loss of the raw feed (see Appendix C). Once the MMBtu per ton of clinker is calculated, the fuel rate and heating value are used to "back calculate" the clinker rate.

While there is uncertainty of values calculated or determined by each of the methods described above, an objective of these tests was to calculate a mass emissions factor, pounds NO (as NO_2) per ton of clinker, which would be representative of these methods and hopefully establish a range of values. This range of values would help establish confidence in the results.

4.3 CONVERSION OF CEMENT KILN EMISSIONS DATA FROM VOLUME BASIS TO MASS BASIS

The emissions data for this program are reported on both a volumetric and mass basis. The calculational procedures used to convert the measured emissions to a mass basis involved information about the fuel feed rate, ignition and entrainment losses, fuel analysis and clinker production rate along with volumetric emissions data. Three methods were used to convert the volumetric emissions data to a mass basis. The methods are discussed in further detail in both Sections 4.3.1 to 4.3.3 and Appendix C. The measurements needed for calculating pounds NO_2 per ton of clinker for each method are presented in Table 8. A comparison of the three methods shows that Methods 1 and 2 require virtually the same measurements (e.g. fuel analysis, ignition, entrainment losses). Method 3 requires no information of the fuel or ignition and entrainment losses. The duct flue gas flow rate and clinker rate are used in Method 3 rather than fuel analysis and entrainment losses.

4.3.1 Method 1

Calculation of pounds NO (as NO_2) per ton of clinker is based on KVB gaseous emissions data (NO , CO_2 , O_2), fuel analysis, fuel HHV and fuel flow rate. The step-by-step procedure used for the calculations leading to pounds NO (as NO_2) per ton of clinker is shown in Appendix C-1. In this approach, information on feed rate and clinker rate from plant instrumentation is not used at all. The CO_2 flue gas per ton of clinker, $^{\text{G}}\text{CO}_2$, is determined from plant feed analyses (0.352 lb CO_2 per lb feed) and an estimated dust entrainment factor of 10 percent. The dry flue gas volume from the fuel per heat input, $^{\text{F}}\text{fuel}$, is based on the ultimate analysis of the fuel and the higher heating value. These two factors are then used with measured CO_2 and O_2 to calculate B, million Btu per ton of clinker.

TABLE 8. MEASUREMENTS NEEDED FOR CALCULATING POUNDS NO₂
PER TON OF CLINKER (METHODS 1, 2, AND 3)

Measurement	Method 1	Method 2	Method 3
NO	x	x	x
O ₂	x	x	x
CO ₂	x	-	x
HHV	x	x	-
%C	x	x	-
%H	x	x	-
%S	x	x	-
%N	x	x	-
%O	x	x	-
Ignition Loss	x	x	-
Entrainment Loss	x	x	-
Duct Velocity	-	-	x
Feeder Revs/ Feeder Speed	-	x	-
Coal Rate	-	x	-
Clinker Rate	-	-	x

x ≡ measurement needed for calculation

4.3.2 Method 2

Calculation of pounds NO (as NO₂) per ton of clinker is based on KVB gaseous emissions data (NO, O₂), fuel analysis, fuel HHV, fuel flow rate and kiln feeder speed (measured by plant instrumentation). The step-by-step procedure used for the calculations leading to pounds NO (as NO₂) per ton of clinker is shown in Appendix C-2. Information on measured CO₂ is not used for the clinker rate and million Btu per ton clinker calculations.

Kiln feeder speed is the logical choice for determining clinker rate because kiln feeder speed is continuously time traceable. Although the kiln feeder rate is an indirect means for determining clinker rate, the data are consistently available compared to clinker weigh belt scale integrator readings. A direct determination of clinker rate using the weigh belt scale was not always possible due to one of two factors. The belt was sometimes off line for repair in which case the clinker from the test kiln is switched over to the weigh belt scale for the sister kiln. Conversely, the weigh belt scale for the sister kiln was off line on occasion which meant all clinker (test kiln and the sister kiln) was measured on the test kiln weigh belt scale.

The calculation of clinker rate from kiln feeder speed is based on 17 feeder revolutions/ton clinker. For the as-found data, a time weighted feeder speed was used with the above factor for daily clinker rate determination. The million Btu per ton of clinker is then determined using fuel flowrate and the higher heating value of the fuel.

4.3.3 Method 3

The third method is based on solving the following equation:

$$\frac{\text{lb NO (as NO}_2\text{)}}{\text{ton clinker}} = \frac{\text{NO}_{\text{ppmv}} \left[\frac{\text{ft}^3}{10^6 \text{ ft}^3} \right] \times \frac{46 \text{ lb NO}_2/\text{mole}}{385 \text{ ft}^3/\text{mole}} \times Q \left[\frac{\text{sft}^3}{\text{hr}} \right]}{\dot{m}_{\text{clinker}} \left[\frac{\text{tons}}{\text{hr}} \right]}$$

where Q = dry standard flue gas volumetric flow rate

$\dot{m}_{\text{clinker}}$ = clinker production rate, from control room

The flue gas flow rate (Q) can be either calculated or measured. The calculated flow rate is based on total hourly mass emissions of CO₂ and volumetric emissions data (CO₂, O₂). Total hourly CO₂ mass emissions (pounds per hour) is based on knowledge of the feed composition (percent CaO and MgO), the coal rate and the feed rate. The methodology for the calculation of stack gas flow rate, as developed by the California Air Resources Board, is shown in Appendix C-4. As noted, the CARB procedure does not account for feed entrainment by the exhaust gas.

Measured flue gas flow rate is based on the dynamic pressure, static pressure and temperature in the duct, and the duct cross sectional area. A complete velocity traverse (4 ports, 10 points per port) was performed at Site 4 in the rectangular duct (84 square feet area, 7.8 m^2) between the multiclone and baghouse. From this traverse, an average velocity was calculated. The emissions sampling point was selected to coincide with the average velocity. Using this average velocity and the duct cross sectional area, a flue gas flow rate could be calculated.

4.3.4 Uncertainty Analysis for Methods 1, 2, 3

A case study example was used to analyze the uncertainty associated with the value of E_T (12.03 lbs NO_2 per ton of clinker) as calculated by the three methods. The accuracy of the measurements used for the three methods is shown in Table 9. The uncertainty of the measurements is based on manufacturer specifications (gaseous emissions data), ASTM methods (fuel analysis), and plant experience (coal, clinker feeder rates). These uncertainty measurements are used to eventually calculate uncertainty of the lbs NO_2 per ton of clinker.

The input data used for each method is shown in Table 10. The input data were devised to satisfy the requirement that E_T (pounds NO_2 per ton of clinker) equals 12.03 for all three methods. The uncertainty for E_T based on the input data and measurement accuracy is shown in Table 11 for each method. The largest calculated uncertainty of E_T was associated with Method 1 (10.5 percent). The uncertainty is equally divided between B (million Btu per ton of clinker) and E (pounds NO_2 per million Btu). The calculation of B is based on feed entrainment loss ignition loss, fuel analysis, and gaseous emissions rather than a direct measure of clinker rate. The feed entrainment loss is the most difficult measurement to quantify accurately. The uncertainty of B using Method 1 is 7.4 percent compared to 5.2 percent using Method 2. Method 2 has been based on a clinker weight belt scale reading (± 5 percent accuracy). The calculation of B using Method 2 is not as intricate as Method 1 and involves less input data and information.

The uncertainty of calculating E_T based on Method 3 is only 5.2 percent. This method is the most attractive of the three from the standpoint of fewer input data. A possible pitfall with this method is that the measured velocity is not representative of the actual duct velocity over the range of operational conditions. An in situ flow measurement device would be needed to monitor flow rates on a continuous basis. Since an in situ flow monitor was not installed in the multicone outlet of the test kiln, a pitot tube was used as a means to measure flow rates over discrete periods of time.

TABLE 9. MEASUREMENT UNCERTAINTY

Measurement	Uncertainty	Reference
NO	±1% full scale	Thermo Electron Corp.
O ₂	±1% full scale	Teledyne
CO ₂	±1% full scale	Beckman
HHV	±50 Btu/lb	ASTM Methods
%C	±0.3%	ASTM Methods
%H	±0.07%	ASTM Methods
%S	±0.10%	ASTM Methods
%N	±0.05%	ASTM Methods
%O	±0.5%	ASTM Methods
Ignition Loss	±0.2%	Site 4
Entrainment Loss	±7%	Site 4
Dynamic Pressure	±0.02 in H ₂ O	
Feed Revs Counter	±1%	Site 4
Coal Rate	±2%	Site 4
Clinker Rate	±5%	Site 4

TABLE 10. METHODS 1, 2, 3 CASE STUDY - INPUT DATA

	Method 1	Method 2	Method 3
NO (3% O ₂), ppm dry:	1,320	1,320	440
O ₂ , % dry:	1.5	1.5	-
CO ₂ , % dry:	19.6	-	12.9
Fuel HHV (mill outlet), Btu/lb:	12,260	12,260	-
Fuel %C:	69.22	69.22	-
%H:	4.64	4.64	-
%S:	0.54	0.54	-
%N:	1.4	1.4	-
%O:	9.92	9.92	-
Ignition Loss (Feed):	0.352	0.352	-
Entrainment Loss:	0.10	0.10	-
Duct Flow Rate (sdcfm):	-	-	158,657
Clinker Rate (from feeder revs counter or clinker belt),	-	41.6	41.6
Coal Rate,	-	9.65	-

TABLE 11. UNCERTAINTY ANALYSIS

x	Method 1		Method 2		Method 3	
	w _x	$\frac{w}{x}$	w _x	$\frac{w}{x}$	w _x	$\frac{w}{x}$
B ($\frac{\text{MMBtu}}{\text{ton clinker}}$) 5.69	0.42	7.4%	0.30	5.3%	-	-
E ($\frac{\text{lbs NO}_2}{\text{MMBtu}}$) 2.11	0.16	7.4%	0.16	7.4%	-	-
E _T ($\frac{\text{lbs NO}_2}{\text{ton clinker}}$) 12.02	1.26	10.5%	1.08	9.0%	0.63	5.2%

w_x: uncertainty

SECTION 5.0

AS-FOUND TEST SERIES AND RESULTS

The as-found test series consisted of data collection for operating conditions as determined by the kiln operators. These operating conditions were duly noted each day by a KVB test crew member. A daily log of significant operation changes and the reason for these changes were also kept.

Seventeen days of as-found data were collected to assess process variability with clinker production. As-found operation is defined as kiln conditions under normal, every day operations; including kiln upsets (e.g. kiln in the hole where burning zone temperature is inadequate for clinker production). Strip charts of the key emissions and kiln operating data for 15 of those days are shown in Appendix E-1. The purpose of presenting these strip charts is to show how kiln operating changes and the magnitude of these changes impact specifically the NO emissions and material temperature. Also, the charts show the steadiness and unsteadiness of kiln operation during the course of the day. Those 15 days represent as-found operating conditions for the calcination, clinkerization and cooling of Type II feed. Two additional days of as-found data were also collected for a Type III feed. As mentioned earlier, the primary differences component-wise between the Type II and Type III feeds is replacement of a portion of the shale component with aluminum oxide and minimal use of iron ore. From a kiln operation perspective, the kiln shell temperature is typically lower with the Type II feed since more feed coats the kiln.

During as-found kiln operation, the daily kiln exit gaseous emissions normally analyzed were nitric oxide (NO), carbon monoxide (CO), carbon dioxide (CO₂), and oxygen (O₂). The O₂, CO₂ and CO data are reported on a dry volume basis and the NO data are reported on a dry volume basis corrected to 3 percent O₂. CO and NO are also reported on a weight per thermal input basis (nanograms per joule). Both Methods 1 and 2 were utilized to compute mass emission factors. The computations were compared as a cross check for the two methods. The clinker rate determination using the kiln feeder speed (Method 2) and a factor of 17 feeder revolutions per ton of clinker seemed to yield too high a number. The clinker weigh belt scale was rarely available for clinker rate determinations and would have been the best means to determine clinker rate. The CO₂ derived clinker rate (Method 1) provided low clinker rate numbers and higher than expected thermal heat input per ton of clinker.

Twelve coal samples, 67 clinker samples, 30 raw feed samples, two multiclude dust samples and two combined feed samples (raw feed plus multiclude dust) were collected. The inventories of coal, clinker, raw feed, multiclude dust and combined feed samples are listed in Appendix E-2. A

multiclone dust sample was analyzed for particle size and chemical composition. The clinker samples were analyzed by both the cement company and KVB for free lime content.

5.1 EMISSIONS DATA SUMMARY

A daily time trace of dry stack NO concentration, corrected to 3 percent O₂, and free lime concentration is presented in Appendix C. These measurements are two of the key components for characterizing kiln operating performance. The nitric oxide (NO) measurement is related to the burn zone temperature which is an indicator that key chemical components of cement (C₂S, C₃S, C₃A, C₄AF) are being formed. The free lime content gives a good measure of how well the kiln feed has been burned. The free lime analyses conducted by KVB and the host site are plotted with NO to show how free lime content is related to the NO concentration (Appendix C). Some overburning was evident based on the low free lime (less than 0.3 percent) and NO concentrations between 600 to 1800 ppm, at 3 percent O₂. Conversely, the underburning (kiln-in-the-hole) was evident based on high free lime content (over 0.8 percent) and NO concentrations less than 400 ppm, at 3 percent O₂.

Table 12 summarizes the daily as-found emissions data on a volumetric and mass basis for the Type II feed (15 days) and the Type III feed (two days). The data on a mass basis--CO and NO (nanograms per joule); clinker rate (tons/hr); million Btu per ton of clinker and pounds NO per ton of clinker--are calculated with Method 1 (Appendix C-1). A statistical summary of the emissions data (volumetric basis) and CO, NO (nanograms per joule) in terms of the arithmetic mean and 95 percent confidence interval is also presented in Table 12. The basis for this summary table is the emissions data recorded on a 15-minute basis during the testing period for each day of the as-found conditions. These average emissions data recorded on a 15-minute basis are presented in Appendix E-4.

Table 13 shows the calculated daily average clinker rate (tons/hour), million Btu per ton of clinker and pounds NO (as NO₂) per ton of clinker using Methods 1 and 2. The calculated percent deviation between the two methods is also shown. The discrepancy of calculated pounds NO (as NO₂) per ton of clinker using Methods 1 and 2 is evidenced by the range of percent deviation from a low of 0.1 percent (10/12) to a high of 33.7 percent (9/28).

A comparison of the clinker rates calculated with Methods 1 and 2 shows that the clinker rate derived from Method 2 is consistently higher. The clinker rate using Method 2 is calculated from the kiln feeder speed chart (continuous readout) and the factor for feeder revolutions per ton of clinker (17). A cross check of the calculated clinker rate from kiln feeder speed was made with the clinker rate determined by the kiln feeder revolutions counter over a timed interval. Table 14 shows the results of the crosscheck. The average calculated clinker rate using the kiln feeder revolutions counter was approximately five percent lower, on the average.

TABLE 12. DAILY AS-FOUND VOLUMETRIC AND MASS EMISSIONS (METHOD 1)

DATE	TEST DURATION		O ₂ VOL % DRY		CO ₂ VOL % DRY		CO PPMV DRY		NO PPMV DRY (3 % O ₂)	
	BEGIN	END	MEAN VAL	CI95	MEAN VAL	CI95	MEAN VAL	CI95	MEAN VAL	CI95
1983										
9/26	1130	1630	2.1	.28	29.7	1.22	--	--	1510	126.17
9/27	915	1600	2	.2	28.7	.62	--	--	1127	148.97
9/28	845	1600	1.7	.13	28.8	.43	--	--	983	65.05
9/29	845	1530	2.1	.62	28.3	.63	--	--	741	181.03
9/30	900	1530	2.5	.09	27.9	.49	--	--	881	59.8
10/ 3	845	1230	2.7	.24	27.3	.59	--	--	1069	104.39
10/ 4	745	1330	2.7	.37	28.1	.68	63	39.35	1096	231.97
10/ 5	815	1530	2	.19	28.2	.65	94	29.69	1225	162.57
10/ 6	745	1045	3.3	1.61	27.7	1.32	65	35.08	1103	119.3
10/ 7	1130	1500	2.9	.74	28.1	1.06	88	32.81	860	187.71
10/10	845	1615	2.7	.33	27.8	1.11	45	6.55	963	87.47
10/11	845	1545	3.4	.35	27.9	.62	33	4.81	974	70.37
10/12	800	1330	3.5	.86	28.3	1.13	42	13.52	977	189.77
10/13	800	1530	2	.23	30	.71	70	19.43	906	81.75
10/14	745	1500	2	.29	29.6	.63	83	30.53	658	103.13
10/24	1000	1500	2.2	.18	29.5	.7	90	22.13	919	206.31
10/25	1015	1415	2.5	.26	28	.64	68	19.44	1021	256.55

DATE	TEST DURATION		CO NG/J		NO NG/J		CLINKER RATE	COAL FUEL RATE	COAL RATE	MMBTU PER TON CLINKER	NO LBS PER TON CLINKER
	BEGIN	END	MEAN VAL	CI95	MEAN VAL	CI95	TONS/HR	TONS/HR	BTU/LB		
1983											
9/26	1130	1630	--	--	1069	91.37	42	9.13	12260	5.30	13.00
9/27	915	1600	--	--	782	104.83	39	9.17	12260	5.78	10.41
9/28	845	1600	--	--	677	43.55	38	9.17	12260	5.91	9.36
9/29	845	1530	--	--	522	139.19	37	8.88	12260	5.82	6.66
9/30	900	1530	--	--	611	43.40	37	8.78	12260	5.77	8.14
10/ 3	845	1230	--	--	734	70.68	36	8.81	12260	6.01	10.29
10/ 4	745	1330	26	14.92	766	163.40	40	8.85	12260	5.48	9.67
10/ 5	815	1530	37	11.03	841	108.99	35	8.8	12260	6.10	12.08
10/ 6	745	1045	22	13.27	593	71.32	35	8.71	12260	6.09	9.84
10/ 7	1130	1500	36	12.11	606	134.93	38	8.14	12260	5.29	7.31
10/10	845	1615	19	2.70	667	58.42	36	8.62	12260	5.86	9.18
10/11	845	1545	14	1.68	687	48.58	35	8.39	12260	5.89	8.89
10/12	800	1330	19	5.64	697	129.99	44	8.38	12260	4.67	7.84
10/13	800	1530	28	7.49	642	60.03	40	8.38	12260	5.09	7.54
10/14	745	1500	33	11.75	461	71.94	39	8.35	12260	5.28	5.69
10/24	1000	1500	37	9.02	648	145.26	41	8.64	12260	5.19	7.76
10/25	1015	1415	28	7.41	709	178.86	37	8.61	12260	5.66	9.30

NO on a mass basis as NO₂

TABLE 13. DAILY AS-FOUND CLINKER RATE, MMBtu/TON CLINKER AND POUNDS NO (AS NO₂) TON/CLINKER USING METHODS 1 AND 2

DATE	CLINKER RATE (TON/HOUR)			MMBTU / TON CLINKER			LBS NO / TON CLINKER		
	METH 1	METH 2	% DEV	METH 1	METH 2	% DEV	METH 1	METH 2	% DEV
1983									
9/26	42	47	11.90	5.30	4.76	11.34	13.00	11.95	8.79
9/27	39	53	35.90	5.78	4.16	35.68	10.41	8.16	27.57
9/28	38	54	42.11	5.91	4.17	41.73	9.36	7.00	33.71
9/29	37	47	27.03	5.82	4.66	24.89	6.66	5.76	15.36
9/30	37	46	24.32	5.77	4.70	22.77	8.14	6.89	18.14
10/3	36	48	31.58	6.01	4.50	33.56	10.29	8.08	27.35
10/4	40	43	7.50	5.48	5.07	8.09	9.67	9.13	5.91
10/5	35	49	40.00	6.10	4.43	37.70	12.08	9.14	32.17
10/6	35	41	17.14	6.09	5.22	16.67	9.84	9.42	4.46
10/7	38	45	18.42	5.29	4.40	20.23	7.31	6.39	14.40
10/10	36	42	16.67	5.86	5.08	15.35	9.18	8.04	14.18
10/11	35	42	20.00	5.89	4.93	19.47	8.89	7.94	11.96
10/12	44	42	4.76	4.67	4.85	4.28	7.84	7.85	.13
10/13	40	46	15.00	5.09	4.48	13.62	7.54	6.83	10.40
10/14	39	45	15.38	5.28	4.52	16.81	5.69	5.00	13.80
10/24	41	50	21.95	5.19	4.26	21.83	7.76	6.65	16.69
10/25	37	39	5.41	5.66	5.37	5.4	9.30	8.92	4.28

Figure 6 shows the time trace of daily mean pounds NO (as NO₂) per ton of clinker (Method 2) for each day of as-found testing conditions. In conjunction with this figure, a bar chart (Figure 7) showing the coefficient of variation for the volumetric NO emissions has been plotted with time. The coefficient of variation ranges from a low of 14.5 percent to a high of 57.8 percent. The large dispersion from the mean (time weighted average coefficient of variation of 31 percent) shows that the as-found daily cement kiln emissions (volume basis) are extremely variable.

The time weighted average lb NO (as NO₂) per ton of clinker for the as-found data is 8.83 (4.42 g NO₂/kg clinker) based on Method 1 and is 7.96 (3.98 g NO₂/kg clinker) based on Method 2. Figure 8 shows the distribution of emissions factors on a lb NO (as NO₂) per ton of clinker basis using Method 2. Based on approximately 90 hours of data, the percentage difference between the two weighted averages is approximately 10.9. A T-test was run on the two samples of data (Methods 1 and 2) to determine if the two means differ significantly. The calculated test statistic of 4.19 exceeds the $T_{0.005, 349} = 3.16$ which means the null hypothesis is rejected and the difference in the two mean values is highly significant. There is greater than 99 percent change that the difference in the mean emissions factors between Methods 1 and 2 is real. The rejection of the null hypothesis H_0 results in a Type I error.

TABLE 14. COMPARISON OF CLINKER RATE CALCULATIONS USING KILN
FEEDER SPEED STRIP CHART AND KILN FEEDER REVS INTEGRATOR

Test No.	Kiln Feeder Speed (from strip chart)	Calculated Clinker Rate	Kiln Feeder Speed (from revs counter)	Calculated Clinker Rate	Percent Deviation
9/28-1	15.8	55.76	15.0	52.93	-5.35
-2	14.7	51.88	13.6	48.00	-8.08
-3	15.5	54.70	14.8	52.23	-4.73
-4	16.0	56.47	15.2	53.64	-5.28
9/30-1	13.7	48.35	13.0	45.87	-5.41
-2	12.1	42.70	11.6	40.93	-4.32
-3	12.5	44.11	11.8	41.64	-5.93
-4	13.6	47.99	12.8	45.17	-1.24
-5	12.5	44.11	11.8	41.64	-5.93
10/04-1	14.5	51.18	14.0	49.42	-3.56
-2	10.2	36.0	9.6	33.88	-5.89
-3	15.0	52.94	13.2	46.59	-13.63
10/06-2	14.5	51.18	13.8	48.7	-5.09
10/07-1	16.5	58.24	16.0	56.47	-3.13
10/13-1	13.0	45.88	12.4	43.76	-4.84
-2	12.5	44.12	12.0	42.36	-4.15
-4	12.5	44.12	11.8	41.65	-5.93
-5	14.2	50.12	13.4	47.30	-5.96
-6	13.0	45.88	12.2	43.06	-6.15
-7	13.5	47.65	13.4	47.30	-0.74
10/14-1	13.3	46.94	13.2	46.59	-0.75
-2	15.5	54.71	13.6	48.00	-13.98
-3	13.9	49.06	13.0	45.88	-6.93
10/24-1	14.0	49.4	15.4	54.34	+9.09
-2	14.5	51.17	14.2	50.11	-2.12
10/25-1	13.0	45.88	11.8	41.64	-10.18
-2	12.0	42.35	11.2	39.53	-7.13

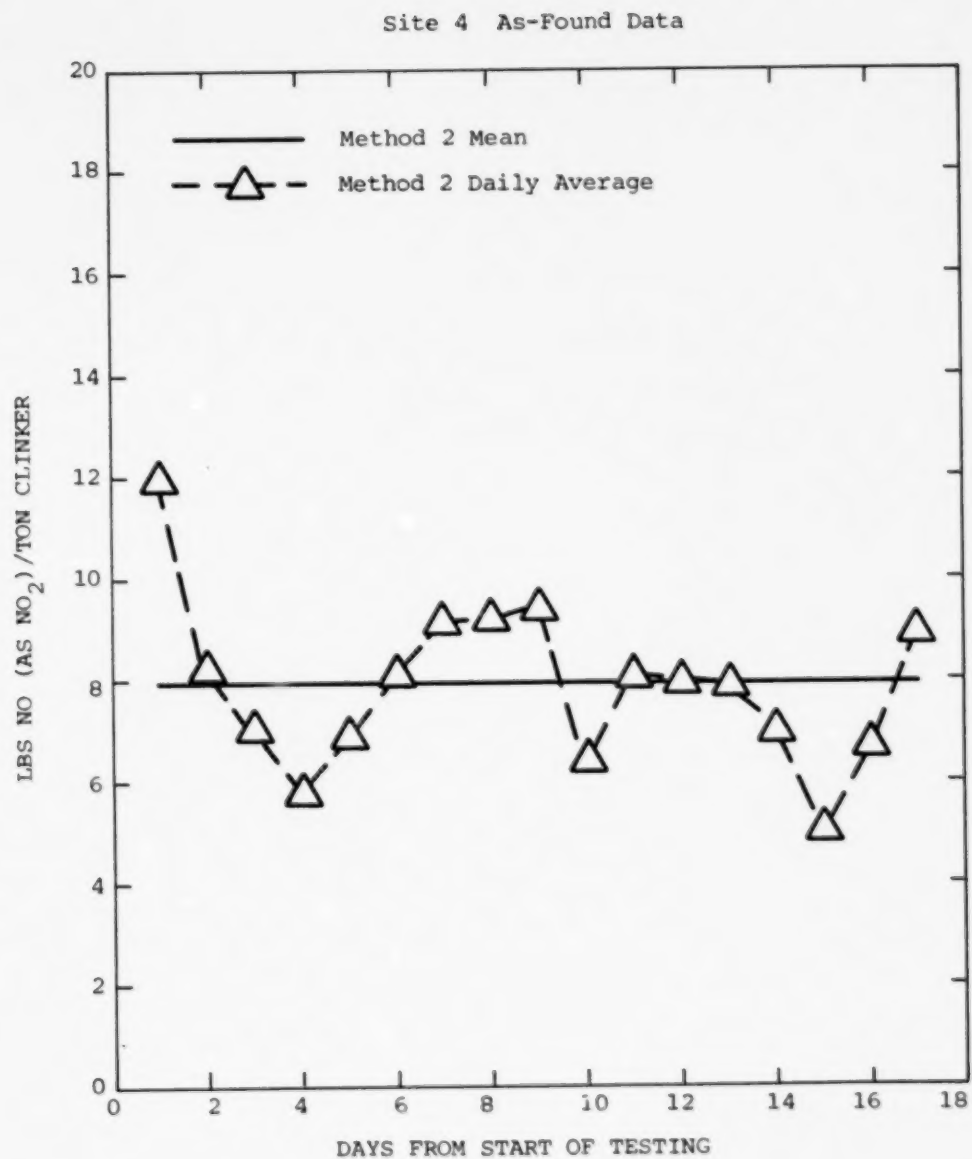


Figure 6. As-Found Average Daily NO Mass Emissions

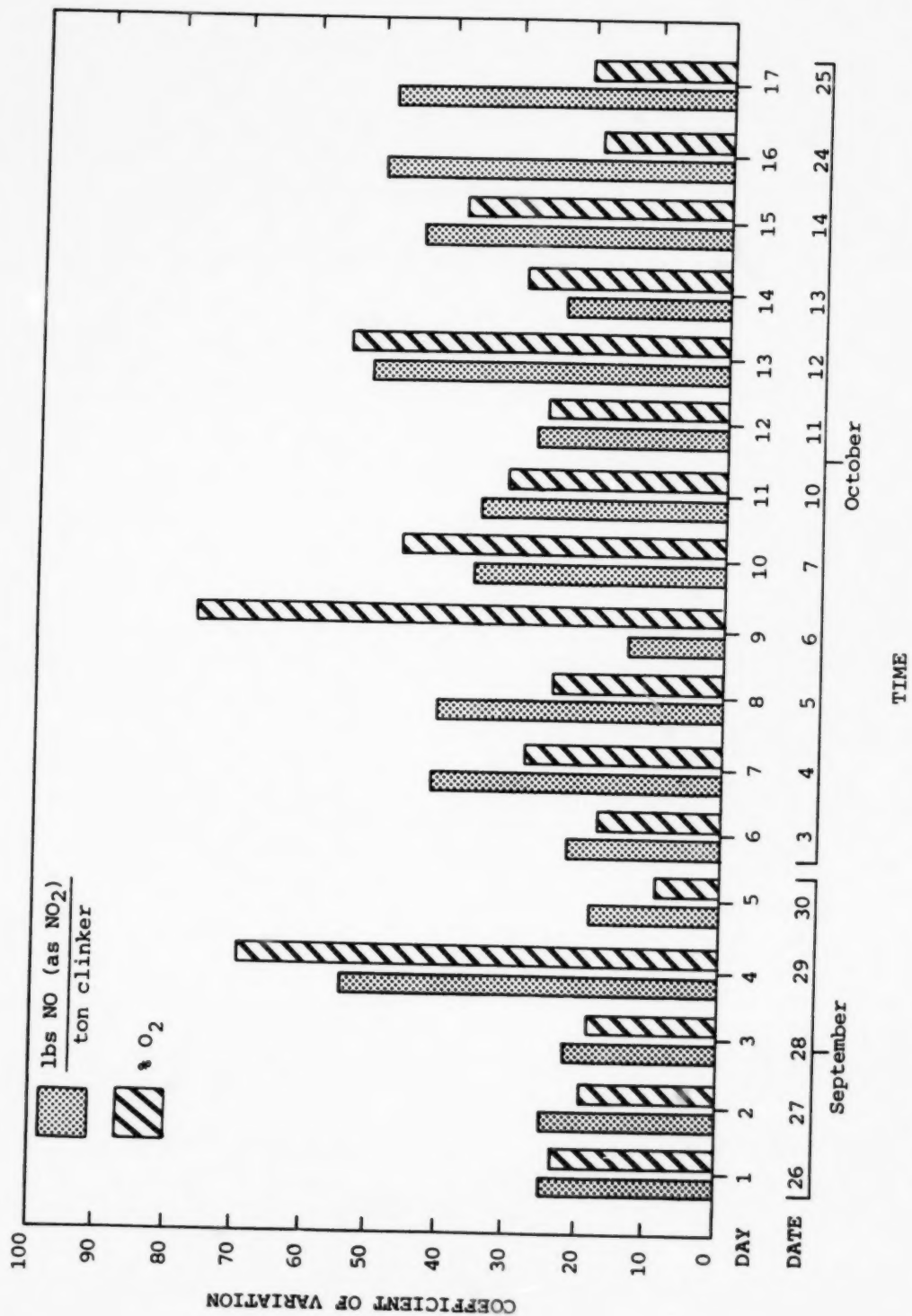


Figure 7. Daily As-Found Coefficient of Variation for NO and O₂ Emissions Data

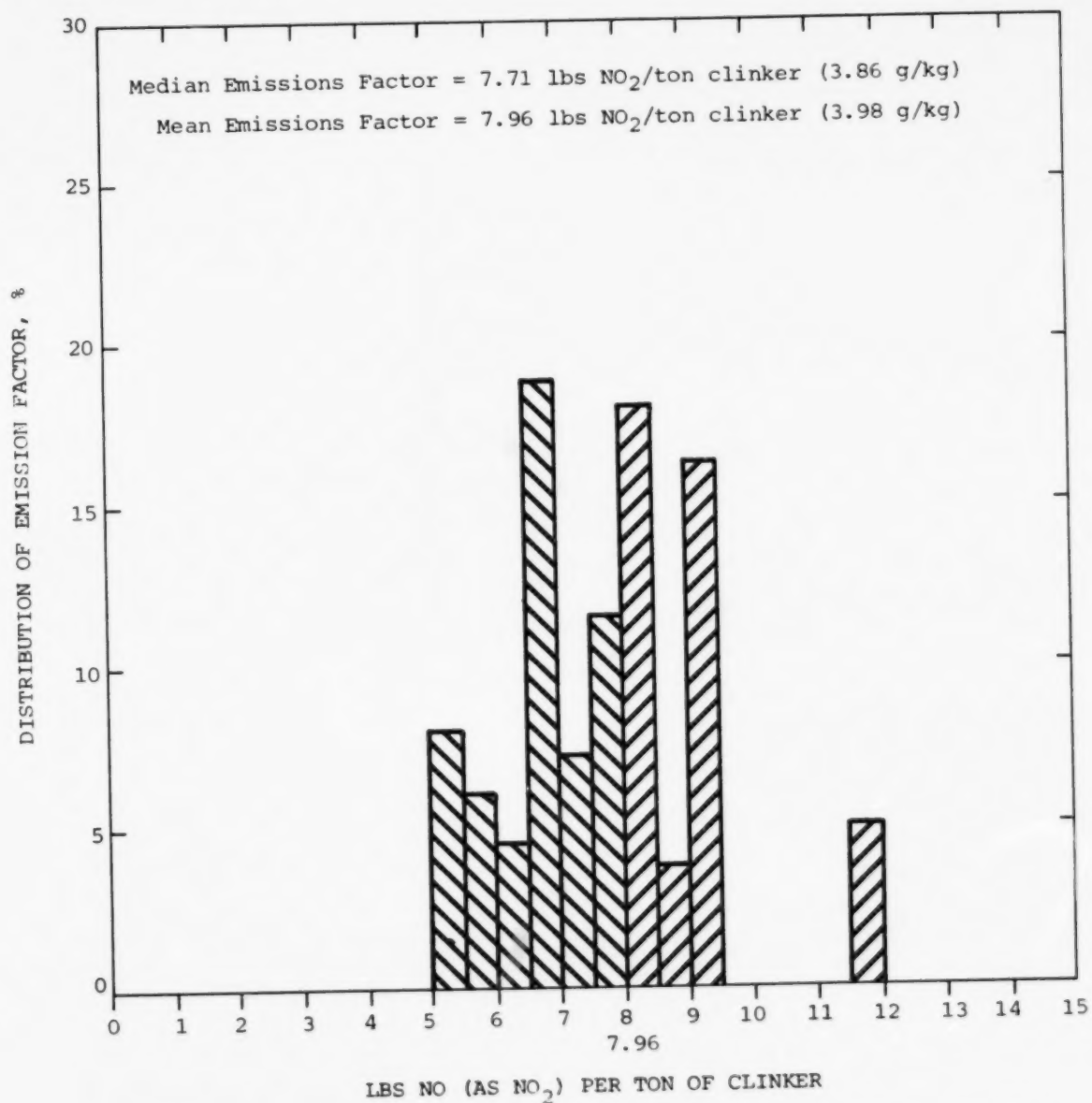


Figure 8. Distribution of Daily As-Found Emission Factor, lbs NO (as NO₂)/Ton Clinker

5.1.1 N₂O Measurement

Three stack gas samples for N₂O analysis were collected for analysis. The average N₂O concentration of 5.7 ppm, uncorrected, with a standard deviation of 1.2 ppm was determined by chromatographic measurements. An N₂O/O₂ ratio of 6.9 ppmv, 2.9 percent O₂ was measured for one of the samples.

5.2 AS-FOUND OPERATION

Clinker in the test kiln is normally burned by maintaining a constant fuel rate and varying the kiln speed to hold the burning zone temperature at the desired level. When the material temperature is higher than the desired level, the kiln speed is increased to decrease the front end temperature. Maintaining stable kiln conditions is a difficult task. If the material temperature and NO rises or falls abruptly, kiln speed step changes are made to counter the rise or fall. The magnitude of the change depends on several factors, including the time rate of change of NO and material temperature.

Two examples of as-found emissions data and control room data are presented to illustrate how material temperature and NO will respond to kiln speed changes. Table 15 summarizes the control room emissions data and operating data from 1200 to 1500 hours based on strip chart data. On October 5, the material temperature was approximately 1426 K (2600°F) for approximately one hour (1200 to 1315 hours) before the temperature and NO started to decrease. The material temperature decreased approximately 16 degrees K (30°F) over the next half hour (1426 K to 1410 K; 2600 to 2570°F) and the NO decreased 300 ppm (1650 to 1350). No operational changes (i.e., kiln speed, cooler grate speed) were made during this time period since the rate of change of material temperature and NO was very small. The time period (1342 to 1412 hours) showed a more significant rate of decrease of material temperature from 1410 K to 1271 K (2570 to 2320°F; $\Delta = 250^\circ\text{F}$). NO decreased from 1350 ppm to 650 ppm ($\Delta = 700$ ppm) during this same time period. At 1409 hours the kiln speed was decreased to 66 rph from 70 rph to reheat the burning zone. Once this speed change was made, the material temperature and NO were on the rise in approximately ten minutes. NO and material temperature continued to rise until the end of the time period considered.

The kiln operations and emissions data of October 11 show how a significantly large change in kiln speed subsequently led to steady kiln operations. Table 16 shows the key emissions data and operating data over approximately a four-hour period. The kiln speed change in question was made at 0942 hours after the NO had plunged approximately 875 ppm (1750 ppm to 875 ppm) in 30 minutes while the material temperature had dropped 180°F (2600°F to 2420°F). Although the NO and material temperature decrease with time was rapid, the kiln speed decrease from 65 rph to 50 rph was equally dramatic in its reversal of the burning zone cooling down too quickly. The effect of this operational change was immediate. Within six minutes, the burning zone was being reheated (material temperature increase) and NO concentration was on the rise. Subsequently, small changes in kiln speed were made to steady kiln operation. The strip chart recordings for NO and kiln speed have been redrawn onto one

TABLE 15. KILN OPERATING AND EMISSIONS DATA
OCTOBER 5, 1983 (1200-1500)

TIME	KILN SPEED (RPM)	DELTA KILN SPEED	NO DELT. PPM NO	MATERIAL TEMP. F	DELTA MATERIAL TEMP.	COOLER CRATE SPEED (RPM)	COOLER AIR TEMP. (F)	UNDERCRATE PRESSURE ("H2O)	KILN HOOD PRESSURE ("H2O) LOW HIGH	KILN END HOUSING PRESSURE ("H2O) LOW HIGH	KILN CHAIN TEMP. F	COMMENTS
1200	68	-	1400	2600	-	13	1720	3.9	-08	-	-	
1206	68	-	1300	+100	+10	13	1720	3.6	-11	-	-	
1212	68	-	1300	2610	+10	13	1700	3.6	-08	-	-	
1218	68	-	1300	2620	-	13	1660	3.5	-08	-	-	
1224	68	-	1350	2620	-	13	1660	3.6	-08	-	-	
1230	68	+2	1350	+50	-	12.5	1660	3.7	-08	-	-	
1236	68	-	1600	2620	-	12.5	1640	3.6	-08	-	-	
1242	70	-	1600	-800	-5	12.5	1640	3.6	-08	-	-	
1248	70	-	1575	2615	-10	12.5	1640	4	-08	-	-	
1254	70	-	1575	2605	-5	12.5	1660	4.1	-11	-	-	
1300	70	-	1600	+25	-5	12.5	1660	4	-11	-	-	
1306	70	-	1675	2600	-	12.5	1700	4	-08	-	-	
1312	70	-	1663	-12	-	12.5	1700	4	-08	-	-	
1318	70	-	1650	-13	-	12.5	1700	3.9	-08	-	-	
1324	70	-	1625	-25	-5	12.5	1690	3.9	-08	-	-	
1330	70	-	1550	-75	-5	12.5	1700	3.9	-11	-	-	
1336	70	-	1550	2395	-	12.5	1690	4	-08	-	-	
1342	70	-	1475	-75	-15	12.5	1700	4.1	-08	-	-	
1348	70	-	1350	-125	-10	12.5	1700	4.2	-11	-	-	
1354	70	-	1150	-200	-30	12.5	1700	4.6	-11	-	-	
1400	70	-	1000	-150	-40	12.5	1700	4.8	-11	-	-	
1406	70	-	875	-125	-20	12.5	1700	5.1	-12	-	-	
1412	66	-4	650	-225	-80	12.5	1740	5.2	-12	-	-	
1418	66	-	650	2340	-20	12.5	1780	5.2	-12	-	-	
1424	66	-	675	+25	+10	13	1800	5.1	-12	-	-	
1430	66	-	675	2350	+10	13	1780	5.2	-12	-	-	
1436	66	-	650	-25	+10	13	1740	5.3	-14	-	-	
1442	66	-	775	+125	+40	13	1740	5.1	-12	-	-	
1448	66	-	775	2420	+20	13	1740	4.9	-11	-	-	
1454	66	-	825	+50	+60	13	1740	4.8	-11	-	-	
1500	66	-	850	+50	+20	13	1740	4.7	-12	-	-	

CHANGE IN KILN SPEED MADE 8 MIN. FOR MAT. TEMP. TO SWING UP, 27 MIN. FOR NOX TO SWING UP.

TABLE 16. KILN OPERATING AND EMISSIONS DATA
OCTOBER 11, 1983 (0800-1148)

TIME	KILN SPEED (RPM)	BELT KILN SPEED	NO. PPH	BELT. NO.	MATERIAL TEMP. F	BELT. TEMP.	COOLER GRATE SPEED (RPM)	COOLER AIR TEMP. (F)	UNDERGRATE PRESSURE (H ₂ O)	KILN HOOD PRESSURE (H ₂ O)	KILN END HOUSING PRESSURE (H ₂ O)	KILN CHAIN TEMP. F	COMMENTS
0800	58	-	1300	-	2580	-	12	1480	3.5	-	-	-	
0804	58	-	1400	+100	2580	-	12	1560	4	-	-	-	
0812	58	+4	1400	-	2600	+20	13	1600	4.5	-	-	-	
0816	42	-	1475	+75	2600	-	13	1650	5	-	-	-	
0820	45	+3	1475	-	2600	-	13	1620	5	-	-	-	
0824	45	-	1425	-50	2600	-20	13	1680	5	-	-	-	
0828	45	-	1425	-50	2600	-20	13	1680	5	-	-	-	
0832	45	-	1450	+25	2560	-20	14	1600	4.5	-	-	-	
0836	45	-	1450	+25	2560	-20	14	1600	4.5	-	-	-	
0840	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0844	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0848	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0852	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0856	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0900	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0904	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0908	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0912	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0916	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0920	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0924	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0928	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0932	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0936	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0940	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0944	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0948	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0952	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
0956	45	-	1450	-	2560	-	14	1600	4.5	-	-	-	
1000	45	+3	1250	+225	2420	-	14	1440	5	-	-	-	
1004	45	+5	1250	+225	2420	-	14	1440	5	-	-	-	
1008	45	-	1000	-250	2500	+40	14	1780	5.5	-	-	-	
1012	45	-	950	-50	2480	-20	14	1780	5.5	-	-	-	
1016	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1020	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1024	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1028	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1032	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1036	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1040	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1044	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1048	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1052	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1056	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1100	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1104	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1108	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1112	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1116	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1120	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1124	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1128	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1132	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1136	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1140	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1144	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	
1148	45	-	925	-25	2480	-20	14	1780	5.5	-	-	-	

figure (Figure 9) to show how closely the NO tracks the kiln speed changes. Also, the strip chart recordings for NO and material temperature have been redrawn onto another figure (Figure 10) to show how NO and material temperature coincide for underburning and overburning conditions.

The two very distinct kiln operation modes of October 11 can be quantified by the coefficient of variation (CV) for NO and O₂ emissions. From 0845 to 1230 hours, the average NO concentration was 1030 ppm, dry, corrected to 3 percent O₂ with a coefficient of variation of 20.7 percent while the average kiln exit O₂ was 2.84 percent with a coefficient of variation of 14.4 percent. During this time period, kiln operation was shifting from a cyclic mode to a steady mode. Operation was steady from 1245 hours until the end of the testing day, 1545 hours (Figure 10). The coefficient of variation for the NO emissions (volume basis) during this time period was approximately 4 percent (mean NO concentration was 891 ppm, dry and corrected to 3 percent O₂) and the coefficient of variation for the O₂ emissions was 17.1 percent (mean kiln exit O₂ of 4.2 percent). Using the coefficient of variation of NO emissions as a measure of kiln operation performance, the CV of 4 percent from 1245 to 1545 hours indicates steady kiln operation. Over the entire as-found data base (17 days, 89.75 hours), the time-weighted average coefficient of variation for NO (volume basis) was approximately 30 percent.

While the operations changes of October 11 enabled steady kiln operation during the afternoon, the normal operation of the kiln was unfortunately not as steady. Controlling the cooling and heating of the burning zone with kiln speed adjustments is a continuous job effort for the kiln operators.

5.3 RAW MIX AND CLINKER CHEMISTRY

The kiln feed samples were analyzed by x-ray fluorescence for oxide content and SO₃. Also, the feed samples were analyzed for oxide content and SO₃ based on a calculated ignited basis. While the feed composition analyses are confidential and thus not reported in Appendix E-2, a series of factors and indices used to characterize burnability are reported. The burnability of the kiln feed is the relative ease or difficulty with which the feed is converted into clinker. The burnability index and factor were calculated for each of the raw feed samples to determine how much variation in feed composition occurred for the Type II and Type III feeds.

The average burnability factor of the 37 Type II feed samples was 108.5 with a standard deviation of 2.15. The average burnability factor of the three Type III feed samples was 117.6 with a standard deviation of 1.00. The criteria used for determining significant changes in burnability is based on Reference 4.

Burnability Factor Change

0-1
2+
3+

Impact

No significant change
Reaction Change
Large change in burnability

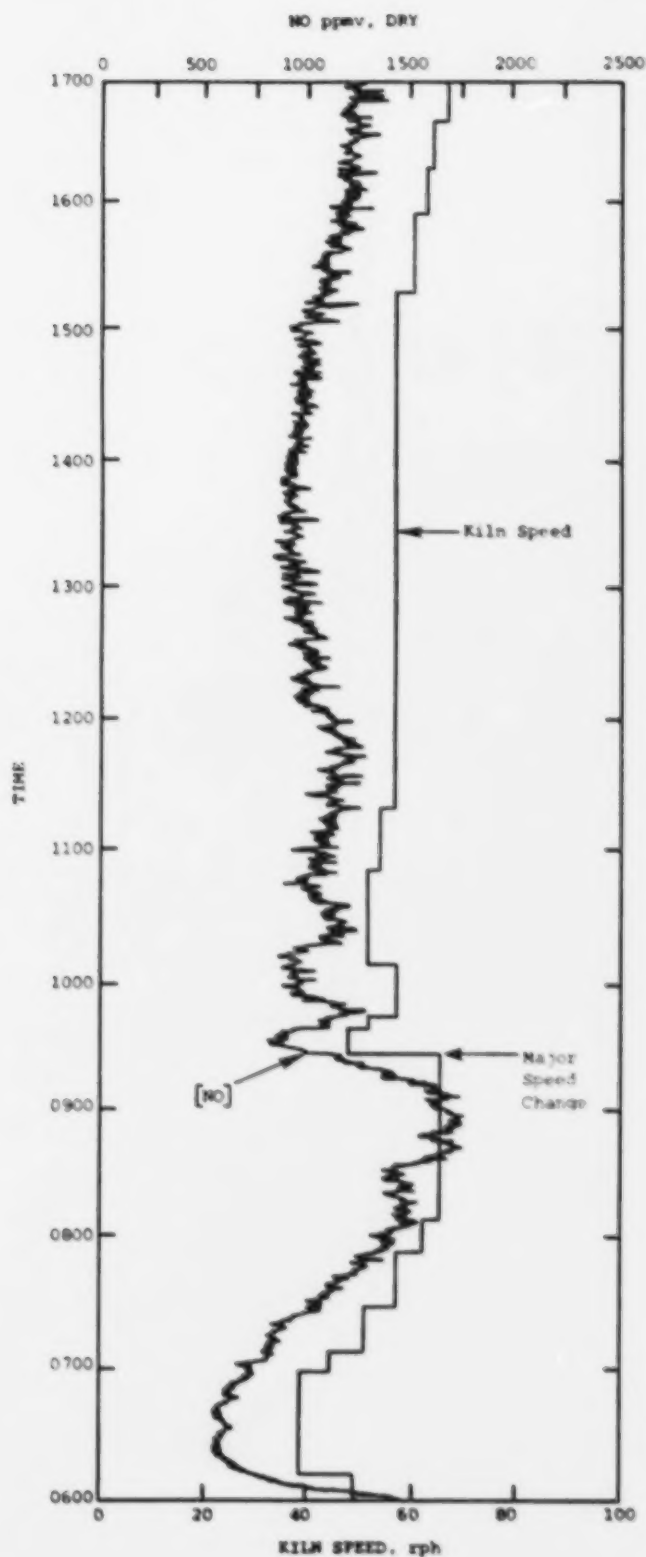


Figure 9. October 11 - Time Trace of NO and Kiln Speed

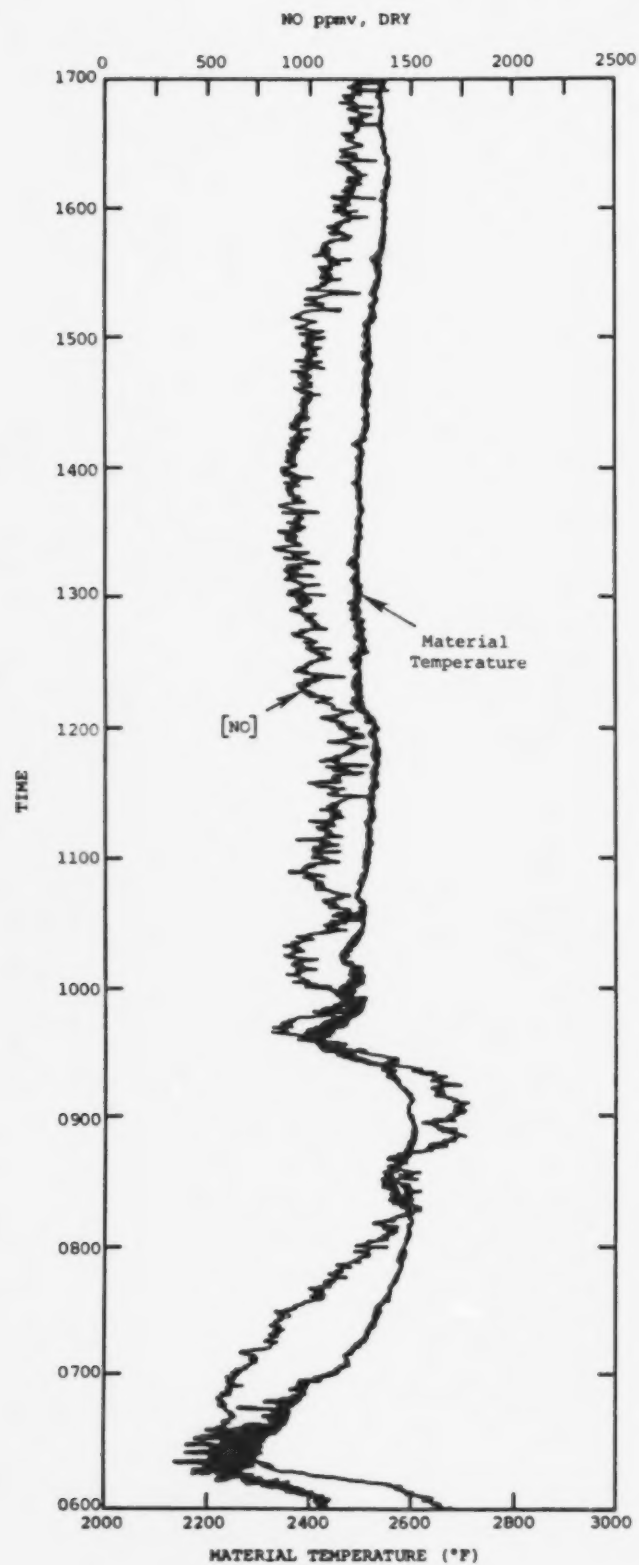


Figure 10.. October 11 - Time Trace of NO and Material Temperature

These large burnability factor changes were observed on occasion but were not related to kiln operation per se. Two examples of the correlation difficulties follow.

On October 3rd and 4th, raw feed samples were collected at approximately 0900 hours and 1045 hours. In both instances, a substantial increase in burnability factor was observed (+5.5 from 0900 hours) which indicates that a harder burner feed will be arriving in the burning zone approximately two hours later. The strip chart data indicate that during the early afternoon of October 3rd, no material temperature problems were experienced. The kiln was running in a fairly steady mode after small cycling during the morning hours. During October 4th, the kiln was cycling in and out of the "hole." The feed composition change at 1045 hours cannot be correlated to the cycling of that day.

Although these calculated values vary from sample to sample and from day to day, the amount of variation which would impact significantly on kiln operation is more difficult to correlate. The variability in mix chemistry was difficult to correlate with changes in kiln stability and nitrogen oxides emissions because the number of raw feed samples in any one particular day was not enough to make any valid correlations.

The short term variability of raw feed samples was also assessed. Raw feed samples were collected every minute for a five minute time interval (0947 to 0951 hours of 10/11/83). The coefficient of variation for the feed composition factors and indices is shown below:

	<u>CV (%)</u>
Lime Saturation Factor	0.8
Silica Ratio	4.3
Percent Flux	0.5
Burnability Index	4.7
Burnability Factor	0.5

The burnability factor range was 1.3 and the burnability factor coefficient of variation was 0.5. These calculations indicate that for these samples, there should not be a significant change in burnability.

The chemically bound nitrogen in the raw feed was measured for one of the samples. That measurement was 24.9 ± 1.3 ppm. Previous work has indicated that 100 ppm N in a kiln feed is equivalent to about 1.0 pounds NO_2 per ton of clinker if all converted (Ref. 5). Thus, the raw feed nitrogen could conceivably contribute 0.2 to 0.3 pounds NO_2 per ton of clinker to the total mass emissions.

The fuel nitrogen content on a weight basis is 1.3 to 1.5 percent. This fuel bound nitrogen content is consistent based on several sample measurements. The consistency eliminates the fuel nitrogen content as a factor in variable NO_x emissions.

Clinker analysis results for the as-found clinker samples showed the variability of tricalcium silicate (standard deviation of approximately 6.6). The variability was traceable to homogenizing silo problems and rock mix difficulties.

SECTION 6.0

NITROGEN INJECTION RESULTS

The specific objective of the nitrogen injection tests was to evaluate the potential of primary air vitiation for reducing NO emissions from a coal-fired cement kiln. Evaluation of the primary air vitiation system was based on "proof of principle" tests conducted on three separate days. These three testing days were November 15 and November 17, 1983 and April 17-18, 1984. Gaseous emissions data were collected along with clinker samples (every 15 minutes), raw feed and coal samples. Type II feed was used throughout these tests. Reference baseline emissions were recorded before and after the nitrogen tests.

The results of the "proof of principle" tests were very important for use as input to establish the final form of a contemplated demonstration rule by the local air quality management district. Figure 11 shows a "baseline" NO emission of approximately 665 ppmv, corrected to 3 percent O₂ and the approximate level of 355 ppmv NO, corrected to 3 percent O₂, required to comply with Demonstration Rule 1112 of the South Coast Air Quality Management District (SCAQMD). The "baseline" emission was based on tests conducted by the California Air Resources Board (CARB) establishing the objective for NO_x control that led to SCAQMD Rule 1112, which is based on an approximate NO reduction of 40 percent (Ref. 6). It was not a specific objective of the research tests being conducted for EPA on this contract to provide the means for compliance with this rule. However, the cooperating cement company and SCAQMD have a significant interest in the results of the test as applied to the proposed rule.

Discussion of the NO mass emissions data for the reference baseline and nitrogen injection tests was based on calculations using Method 2. Base line operation is defined as a specific test condition setup as a point of reference prior to a planned modification (in this case, nitrogen injection). In order to compare NO mass emissions data under similar operating conditions for each test series, linear regression equations were formulated from the data sets. Thus, for a kiln exit O₂ and material temperature common to both test series, the NO (as NO₂) nanograms per joule could be calculated and compared. Linear regression equations were also formulated for pounds NO (as NO₂) per ton of clinker as a function of kiln exit O₂, clinker rate and material temperature. The NO (as NO₂) nanograms per joule was preferred for comparing data sets since calculation of the clinker rate was not needed for this calculation.

6.1 NOVEMBER 15th

The objective of the first day of the nitrogen injection tests was to shakedown the system to insure that nominal flow rates of up to 0.80 m³/s

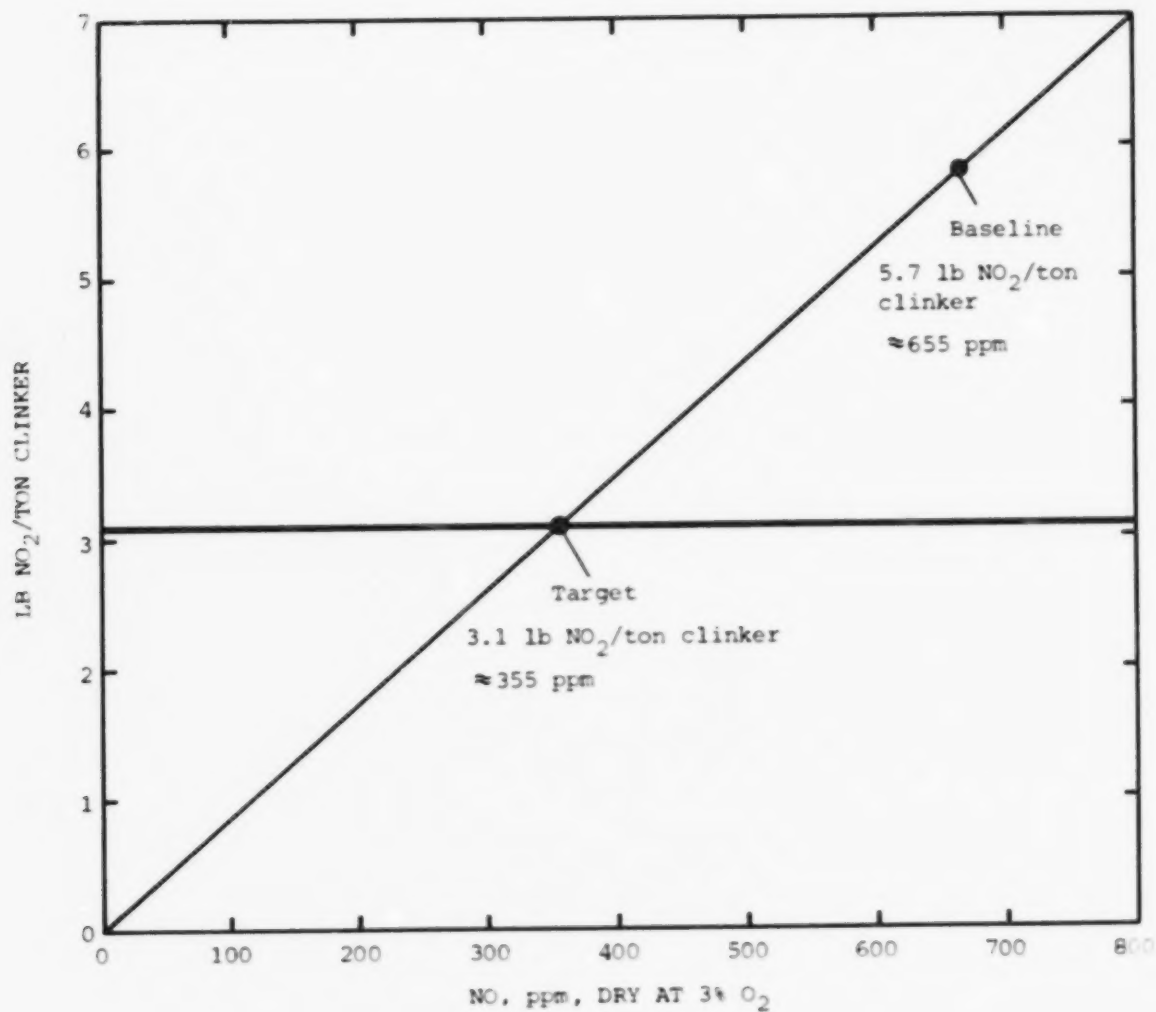


Figure 11. Target NO₂ Mass Emissions Factor

(100,000 scfh) would not adversely affect mill operation or burner stability. The first day of nitrogen testing can be split timewise into two tests: 40 minutes of shakedown at unintentional unsteady flow rates and 50 minutes of a steady flow rate $0.78 \text{ m}^3/\text{s}$ (98,000 scfh). Initially, an average mill outlet O_2 of 19.7 percent was maintained for approximately 40 minutes. Nitrogen flow rate was somewhat unsteady during the initial testing since one of the cryogenic pumps delivering liquid nitrogen to the direct fired heat exchanger for vaporization, was cavitating. This problem was subsequently resolved. The last 50 minutes of testing were run with a steady flow rate of $0.78 \text{ m}^3/\text{s}$ (98,000 scfh) at a delivery temperature of 561 K (500°F) to the primary air duct. The mill outlet average oxygen concentration was approximately 17 percent.

Material temperature was affected during the 90 minutes of the nitrogen injection test. During the first 20 minutes of nitrogen injection, material temperature dropped about 28 K (50°F). However, the temperature remained fairly steady for approximately one hour thereafter. Material temperature decreased approximately 56 K (100°F) in the last 20 minutes of the nitrogen injection test. This temperature change during the latter stages of nitrogen injection could have been due in part to kiln speed changes. The kiln speed was raised from 74 rph* to 85 rph in the span of 24 minutes during the latter stages of the test. Kiln speed was adjusted because the kiln front end was too hot with subsequent coating loss. The kiln shell temperature was higher than normal for both the test kiln and the adjacent sister kiln. The kiln operator felt that the reason for the high kiln shell temperatures was that the feed mix was easier to burn.

Any adverse impact of nitrogen on material temperature was masked by kiln speed changes necessitated by the easy-to-burn kiln feed mix. When nitrogen was shut off, there was an immediate upturn in material temperature and subsequent fluctuation of material temperature which may have been due to both nitrogen shut-off and kiln speed changes made a few minutes prior to shut-off of the nitrogen.

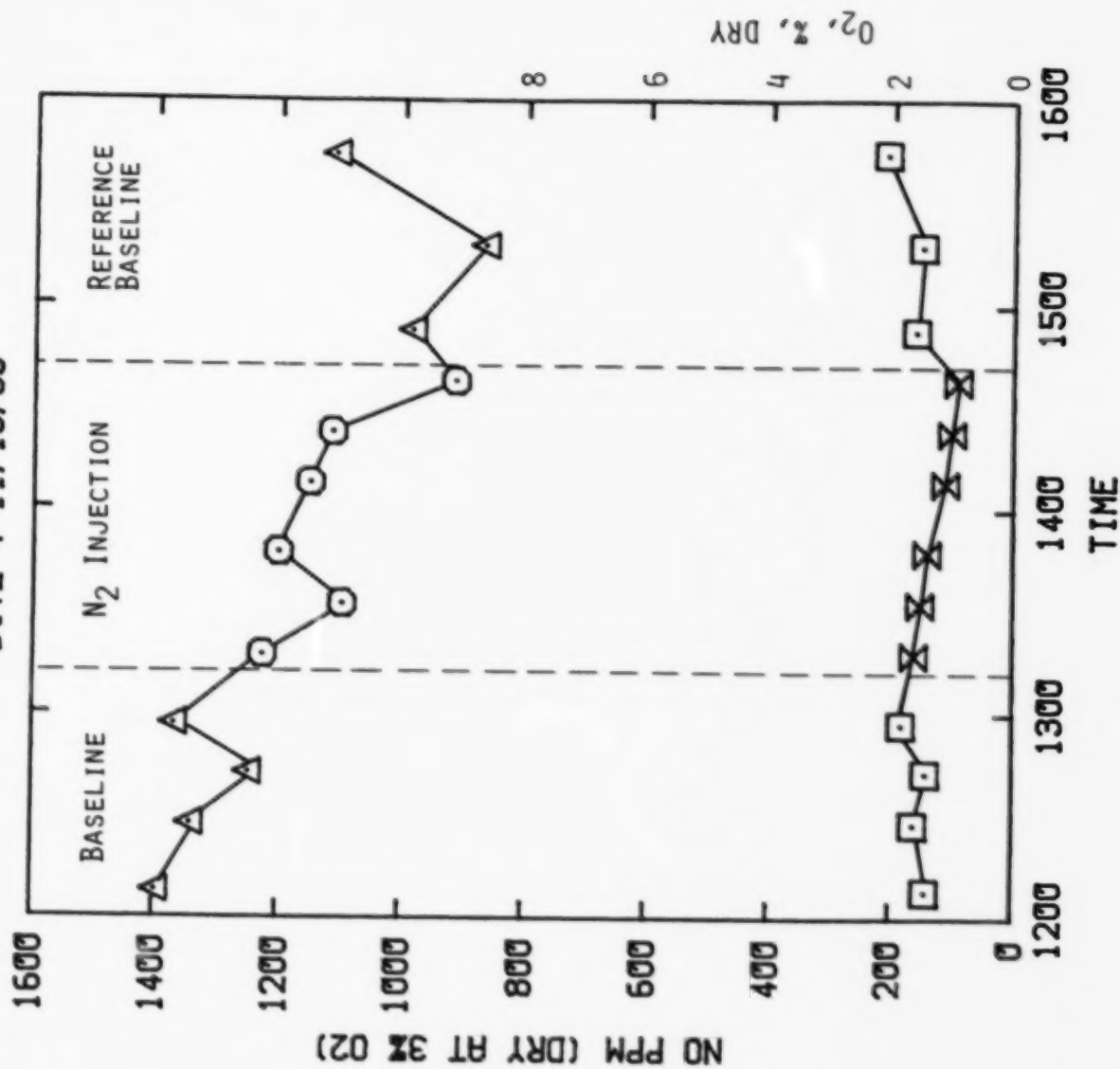
Figure 12 shows the baseline and nitrogen injection test data for NO (ppmv, at 3 percent kiln exit O_2) and kiln exit O_2 (percent, dry). Qualitatively, the figure shows that kiln exit O_2 decreased approximately 0.5 to 0.75 percentage points. NO emissions decreased over the course of the nitrogen injection tests. The extent of NO reduction with nitrogen injection was more difficult to quantify because kiln speed changes affect NO emissions.

Clinker analysis shows that the tricalcium silicate and dicalcium silicate for baseline and nitrogen injection showed very little variation. The difference of the averages between baseline and nitrogen injection was 0.40 for tricalcium silicate and 0.09 for dicalcium silicate.

The objective for the first day of testing was achieved; nitrogen could be injected with no detrimental effect on coal mill operation and no obvious

*rph = revolutions per hour

SITE 4 11/15/83



□ △ × ○

BASELN O₂

BASELN NO

N₂ INJT O₂

N₂ INJT NO

N₂ Injection -
(1309-1445)

Figure 12. Time Trace of NO and O₂ (November 15th)

effect on flame stability. The results with regard to the effect of N_2 injection on NO_2 emissions were inconclusive at 17 percent carrier air O_2 .

6.2 NOVEMBER 17th

A longer term nitrogen injection test (approximately 3-1/2 hours) at higher N_2 flow rate was performed on November 17th. Figure 13 shows baseline and nitrogen injection emissions data for NO (ppmv, at 3 percent kiln exit O_2), and kiln exit O_2 (percent, dry). The testing can be divided into seven distinct time segments based on tests with and without nitrogen injection and kiln operation change. These time segments and test descriptions are listed below and are discussed in the following paragraphs:

- . 0636-0802 -- reference baseline
- . 0809-0927 -- nitrogen injection (143,000 scfh)
- . 0935-1025 -- nitrogen injection (143,000 scfh) plus kiln hood draft adjustment
- . 1038-1052 -- nitrogen injection (178,000 scfh)
- . 1053-1107 -- nitrogen injection (198,000 scfh)
- . 1117-1130 -- nitrogen injection (198,000 scfh), high CO
- . 1132-1201 -- reference baseline

Table 17 statistically summarizes for each time segment the NO mass emissions along with other key emission data, mill outlet O_2 , kiln speed and material temperature. The three statistics reported are the arithmetic mean sample, standard deviation and 95 percent confidence interval. Table 18 summarizes the linear regression analyses for the two reference baselines and nitrogen injection tests. A pre-nitrogen injection and post nitrogen injection baseline are used as reference data points from which a NO reduction might be observed. Kiln operating conditions changed significantly from the first baseline to the second baseline tests (i.e., material temperature, kiln exit O_2 , kiln speed, etc.). The dependent process variables chosen for the linear regression analysis was NO (as NO_2) nanograms per joule. The NO (as NO_2) nanograms per joule was correlated with material temperature and kiln exit O_2 . A correlation of the dependent process variable (pounds NO (as NO_2) per ton of clinker) with the independent process variables (material temperature, kiln speed and kiln exit O_2) was not pursued since the clinker rates as determined by the kiln feeder speed were erratic. However, the lb NO (as NO_2) per ton of clinker are reported for comparison between each time segment. The objective of the regression analyses is directed at establishing normalized operating conditions (e.g., same kiln exit O_2 and material temperature) by which NO emissions can be reviewed for baseline and nitrogen injection tests.

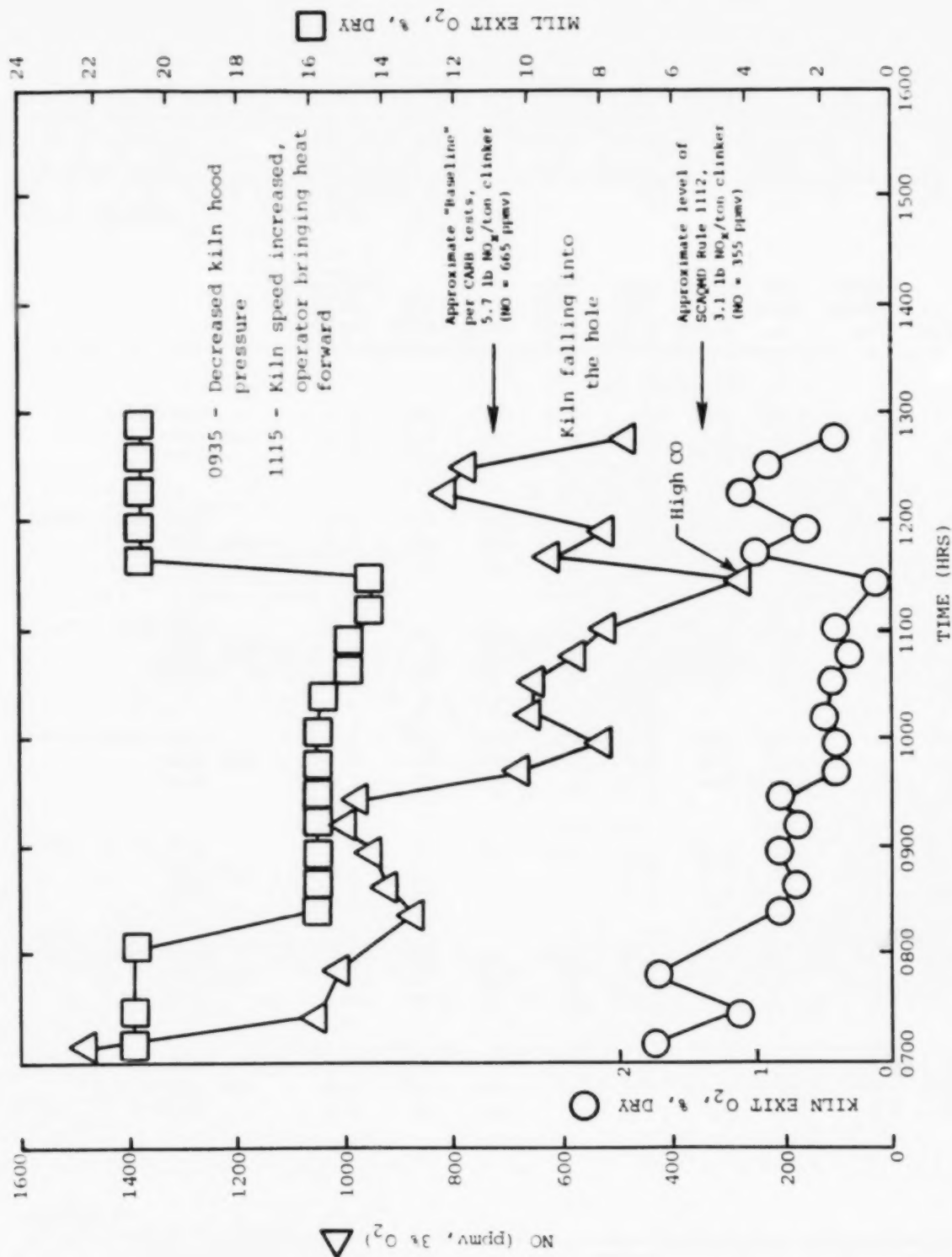


Figure 13. Time Trace of NO and O₂ (November 17th)

TABLE 17. KILN EMISSIONS AND OPERATING DATA SUMMARY

NOVEMBER 17, 1983

DATE: 11/17/83

TIME	NO AS NO2* LBS/TON CLINKER	NO NG/J	NO PPM 3% O2	MAT. TEMP. (F)	KILN EXIT O2, %	KILN EXIT CO2, %	MILL OUTLET O2, %	KILN SPEED RPH	CO NG/J
(0636 -0802) MEAN	0.9	981	1320	2523	1.5	29.6	20.9	75	46
STD. DEV.	1.9	219	290	48	0.3	0.8	0.0	2	50
CI95	1.0	121	160	27	0.2	0.4	0.0	1	27
(0809 -0927) MEAN	6.4	724	966	2479	0.8	29.1	15.7	78	110
STD. DEV.	0.9	113	149	22	0.3	0.6	0.2	2	85
CI95	0.5	63	82	12	0.2	0.3	0.1	1	47
(0935 -1025) MEAN	4.3	494	658	2426	0.4	29.7	15.7	79	222
STD. DEV.	0.8	7	115	28	0.2	0.5	0.3	0	145
CI95	0.5	58	77	19	0.1	0.3	0.2	0	97
(1038 -1052) MEAN	4.1	473	630	2410	0.3	29.2	15.1	79	154
STD. DEV.	0.3	32	42	9	0.2	0.5	0.1	0	139
CI95	0.2	21	28	6	0.1	0.3	0.0	0	93
(1053 -1107) MEAN	3.6	425	561	2415	0.4	29.3	14.4	82	179
STD. DEV.	0.3	37	49	0	0.2	0.6	0.2	0	178
CI95	0.2	22	29	0	0.1	0.3	0.1	0	108
(1117 -1131) MEAN	1.8	216	286	2366	0.1	29.5	14.4	82	459
STD. DEV.	0.8	97	129	14	0.0	0.7	0.5	0	248
CI95	0.5	54	71	8	0.0	0.4	0.7	0	137
(1133 -1201) MEAN	3.7	448	587	2454	0.8	30.7	21.0	84	105
STD. DEV.	0.8	100	131	18	0.4	0.9	0.0	0	208
CI95	0.3	38	50	7	0.2	0.4	0.0	0	79

*METHOD 2

TABLE 18. REGRESSION ANALYSES FOR BASELINE AND NITROGEN INJECTION TESTS

NOVEMBER 17, 1983

TIME DURATION BEGIN END	NO. OF DATA PTS.	REGRESSION EQUATIONS	CORR. STAND. COEF. ERR.
REFERENCE BASELINE:			
0636 0802	15	NG NO(AS NO2) ----- = -9943 + 103.3 * (KILN EXIT O2, %) + 4.27 * (MAT. TEMP.,F) JOULE	0.98 44.2
NITROGEN INJECTION 143,000 SCFH:			
0809 0927	15	NG NO(AS NO2) ----- = -8274 + 282.6 * (KILN EXIT O2, %) + 3.54 * (MAT. TEMP.,F) JOULE	0.91 49.8
NITROGEN INJECTION 143,000 SCFH; KILN HOOD PRESSURE CHANGE:			
0935 1025	11	NG NO(AS NO2) ----- = -5308 + 236.7 * (KILN EXIT O2, %) + 2.35 * (MAT. TEMP.,F) JOULE	0.96 27.5
NITROGEN INJECTION 178,000 SCFH:			
1038 1052	11	NG NO(AS NO2) ----- = 348.8 + 122.2 * (KILN EXIT O2, %) + .034 * (MAT. TEMP.,F) JOULE	0.81 20.7
NITROGEN INJECTION 198,000 SCFH:			
1053 1107	13	NG NO(AS NO2) ----- = -36186 + 127.6 * (KILN EXIT O2, %) + 15.14 * (MAT. TEMP.,F) JOULE	0.84 22.1
RETURN TO BASELINE:			
1133 1201	29	NG NO(AS NO2) ----- = -626.7 + 127.5 * (KILN EXIT O2, %) + 0.396 * (MAT. TEMP.,F) JOULE	0.55 86.1

6.2.1 Reference Baseline - No Nitrogen

The baseline emissions data (0636 to 0802 hours) were recorded for approximately an hour and a half prior to the nitrogen injection tests. Average baseline emissions were 8.97 lb NO (as NO₂) per ton of clinker with a standard deviation of 1.9 (Table 17). The coefficient of variation was 21 percent which was somewhat less than the mean coefficient of variation determined from the as-found data (31 percent). From the kiln operation viewpoint, the NO data spread as quantified by the coefficient of variation indicated the kiln was operating in a steadier condition than the average as-found condition. The kiln exit baseline oxygen averaged approximately 1.5 percent with a standard deviation of 0.34 percent.

Correlations were calculated between kiln exit NO emissions data with kiln exit O₂ and material temperature separately and combined. There is a small correlation between kiln exit O₂ and NO emission levels

$$(\text{ng NO as NO}_2 \text{ per joule} = 651.9 + 215.4 \times \text{kiln exit \% O}_2; r = 0.33)$$

but a very strong correlation between material temperature and NO emission levels

$$(\text{ng NO as NO}_2 \text{ per joule} = -10129 + 4.40 \times \text{Mat. Temp., } ^\circ\text{F}; r = 0.97).$$

Approximately 11 percent of the variation in NO emissions is associated with the variation in kiln exit O₂ concentration while 94 percent of the variation in NO emissions is associated with material temperature. The kiln exit O₂ and material temperature were then used to generate a linear regression equation for the dependent process variable, ng NO as NO₂ per joule. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = -9943 + 103.3 \times \% \text{ O}_2 + 4.27 \\ \times \text{Mat. Temp., } ^\circ\text{F}; r = 0.98)$$

demonstrates that approximately 97 percent of the variation in NO emissions is associated with kiln exit O₂ and material temperature. The average value of 985 ng/J NO (as NO₂) was calculated from the average kiln exit O₂ and material temperature during this time period.

6.2.2 Nitrogen Injection (143,000 scfh)

An initial nitrogen flow rate of 1.14 m³/s (143,000 scfh) was injected into the primary air stream from 0809 to 0927 hours. The average mill outlet oxygen was 15.7 percent over this time period. Average NO mass emissions were 6.36 pounds NO as NO₂ per ton of clinker with a standard deviation of 0.93. The NO emissions coefficient of variation was 14.6 percent indicating that kiln operation was very steady over this interval. The decrease in NO mass emissions from baseline (8.97 pounds NO as NO₂ per ton of clinker) coincided with a decrease of kiln exit O₂ to approximately 0.8 percent from an average of 1.5 percent at baseline.

The nitrogen injection was expected to decrease the kiln exit O_2 but not by the magnitude indicated. During this time period, the cooler grate speed was increased from 16.0 to 16.2 rpm while secondary air temperature was decreasing. The cooler grate speed increase was reflected in lower undergrate pressures and increased air volume flow to the hood. Kiln hood pressure increased during this time period. All of these operating parameters point to increased air volume flow to the kiln and consequently higher kiln exit oxygen concentrations.

The average material temperature decreased from 1657 K (2523°F) baseline to 1632 K (2479°F) with nitrogen injection. Correlations of NO emissions data with kiln exit O_2 and material temperature separately and combined were made to compare with baseline regression equations. A more significant correlation between kiln exit O_2 and NO emission levels was observed with the nitrogen injection case compared to the reference baseline condition. The correlation coefficient of 0.62 was calculated for nitrogen injection while a correlation coefficient of 0.33 was calculated for reference baseline. Conversely a less significant correlation between material temperature and NO emission levels was observed with the nitrogen injection case compared to the reference baseline condition. A correlation coefficient of 0.57 was calculated for nitrogen injection while a correlation coefficient of 0.97 was calculated for reference baseline. Kiln exit O_2 and material temperature were then used to generate a linear regression equation for the dependent process variable, ng NO as NO_2 per joule. The equation

$$(\text{ng NO as } NO_2 \text{ per joule} = -8274 + 282.6 \times \% O_2 + 3.54 \\ \times \text{Mat. Temp., } ^\circ\text{F}; r = 0.91)$$

demonstrates that approximately 84 percent of the variation in NO emissions was associated with kiln exit O_2 and material temperature. An average value of 728 ng/J NO (as NO_2) was calculated from the regression equation using the average kiln exit O_2 of 0.8 percent and the material temperature of 2479°F.

The linear regression equations for NO as NO_2 ng/J (kiln exit O_2 , material temperature) were used to generate a family of curves to determine the reduction potential of nitrogen injection from reference baseline conditions. Figure 14 shows a family of curves for NO (ng/J) versus kiln exit O_2 for three material temperatures encountered at baseline conditions--1644 K (2500°F), 1658 K (2525°F), 1672 K (2550°F) and nitrogen injection conditions--1630 K (2475°F), 1644 K (2500°F), 1658 K (2525°F). A kiln exit O_2 range of 0.7 to 2.1 percent was used for reference baseline conditions and 0.4 to 1.5 for nitrogen injection conditions. The figure shows that if a constant kiln exit O_2 (1 percent) and material temperature (2500°F) had been maintained for both baseline (mill outlet O_2 = 20.9 percent) and the nitrogen injection test (average mill outlet O_2 = 15.7 percent) no visible change in NO emissions would occur. In fact, the net result based on data generated from the regression analyses would show a slight increase of approximately 2.8 percent from

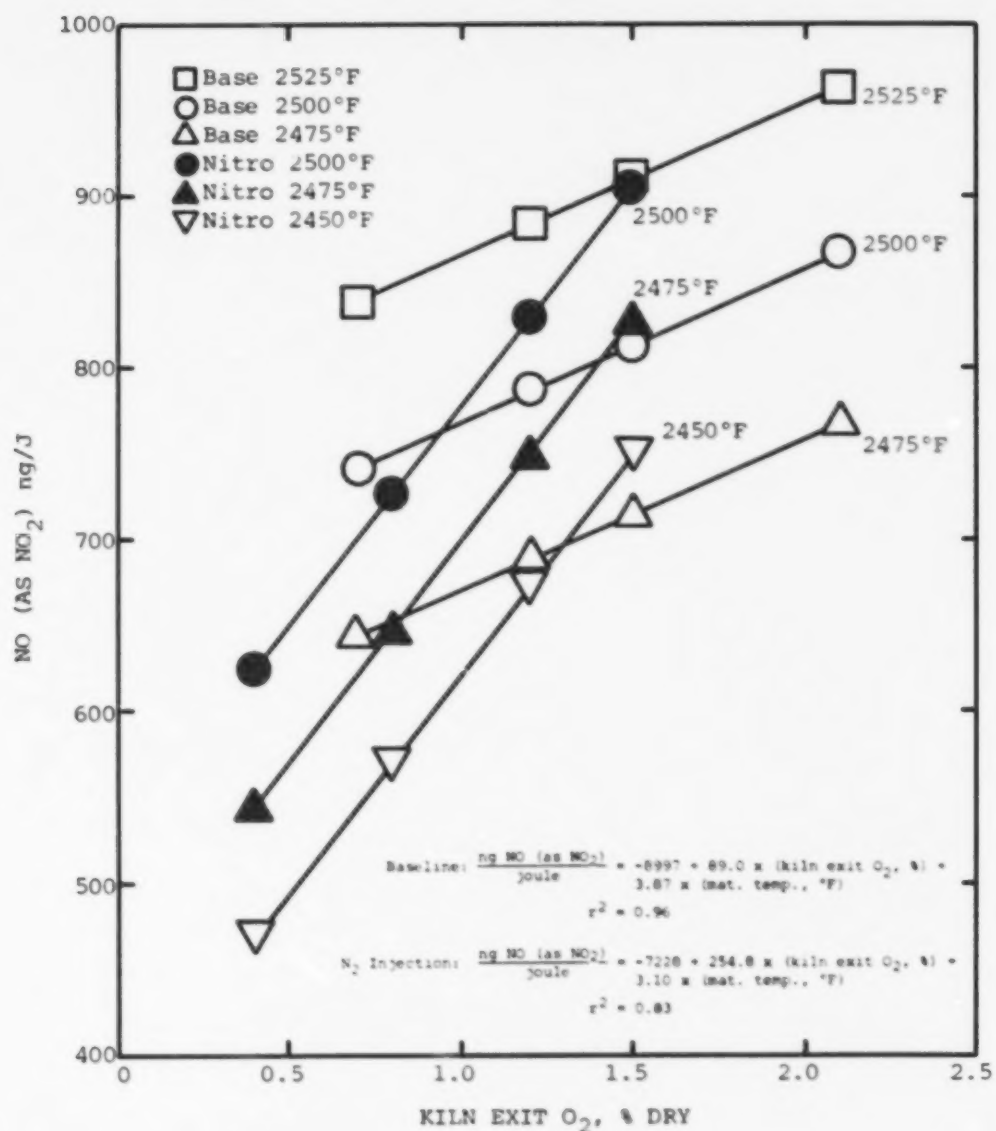


Figure 14. Regression analyses for NO (as NO₂) ng/joule as a function of material temperature and kiln exit oxygen for baseline and nitrogen injection data.

reference baseline conditions. This result, based on normalized kiln operations data under both conditions, is much different from the net decrease of 26.1 percent based on an NO mass emissions reduction due to decreased kiln exit O₂ and material temperature.

Figure 14 shows that for a common material temperature (e.g., 2500°F) under reference baseline and nitrogen injection tests, lowering the kiln exit O₂ with nitrogen below the critical value will yield a positive result. The percent reduction would become more significant at lower kiln exit O₂'s until the combustibles limit would be encountered. At 0.5 percent kiln exit O₂, a theoretical reduction of 8 percent is expected from baseline conditions.

6.2.3 Nitrogen Injection (143,000 scfh) Plus Kiln Hood Draft Adjustment

Emissions data and kiln operations data collected from 0935 to 1025 hours showed another decrease in NO, O₂ and material temperature. The emissions and material temperature were not due to a change in nitrogen injection flow rate 1.14 m³/s (143,000 scfh) but rather to a kiln hood pressure change. The operational change was made at 0930 hours to avoid the kiln hood pressure from becoming positive. When hood pressure becomes too high, the damper(s) on the excess air chimneys can be opened reducing the total secondary air introduced to the kiln. The clinker cooler has excess air chimneys to regulate the amount of excess air which escapes through the cooler chimney.

When the kiln hood pressure was made more negative (from 0.06 inches H₂O negative to 0.15 inches H₂O negative), the kiln exit O₂ decreased from an average of 0.8 percent to an average of 0.4 percent. The reason that the kiln exit O₂ decreased in this fashion is that less secondary air enters the kiln. Average material temperature decreased from 1671 K (2504°F) to 1615 K (2448°F). Average NO mass emissions decreased from 724 ng/J, 6.36 lb per ton of clinker to 494 ng/J, 4.29 lb per ton of clinker. A more negative kiln hood pressure would tend to alter the flame geometry pattern and cool the front end. The emissions data and material temperature followed this tendency. During this time segment, the NO mass emissions coefficient of variation was 18.6 percent which indicated kiln operation was fairly steady.

The linear regression analyses for NO as NO₂ ng/J as a function of kiln exit O₂ and material temperature separately showed that NO as NO₂ ng/J was more dependent on material temperature than kiln exit O₂. Approximately 34 percent of the variation in NO emissions is associated with the variation in kiln exit O₂ concentration while 59 percent of the variation in NO emissions is associated with the variation in material temperature. The kiln exit O₂ and material temperature were then used to generate a linear regression equation for the dependent process variable, ng NO as NO₂ per joule. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = -5308 + 236.7 \times \% \text{ O}_2 + 2.35 \times \text{Mat. Temp.,} \\ ^\circ\text{F}; \quad r = 0.96)$$

demonstrates approximately 92 percent of the variation in NO emissions about the average value of 488 ng/J is associated with kiln exit O₂ and material temperature.

The NO mass emissions value (ng per joule) for this time segment was 50.5 percent below the reference baseline value of 985 ng per joule (0636 to 0802 hours) and 32.6 percent below the value prior to the kiln hood draft change (0809 to 0925 hours). The question is how much of this percentage change is related to material temperature and kiln exit O₂ changes. The basis for the assessment between the reference baseline and nitrogen injection testing (0836 to 0925 hours) is a kiln exit O₂ of 0.8 percent and a material temperature of 1644 K (2500°F). The calculated reference baseline number using the regression equation is 886 ng/J NO (as NO₂) compared to nitrogen injection testing (0836 to 0925 hours) emissions factor of 802 ng/J NO (as NO₂) and the calculated emissions factor of 756 ng/J NO (as NO₂). The delta normalized to a common material temperature and kiln exit O₂ is approximately 15.2 percent between reference baseline and nitrogen injection with kiln hood pressure change. This delta (15.2 percent) is far less than the percent difference calculated from the average measured (51.3 percent). It should be kept in mind that the data overlap between these two conditions was very small.

6.2.4 Nitrogen Injection (178,000 scfh)

While the kiln hood pressure was steady for the last two hours of the nitrogen injection tests, two more increases in nitrogen flow rate were made. The mill outlet O₂ was lowered from an average of 15.7 percent to an average of 15.1 percent at 1030 hours and then decreased to an average of 14.4 percent at 1050 hours and maintained at this level until the end of the nitrogen injection tests. The nitrogen injection flow rate increase at 1030 hours to 1.42 m³/s (178,000 scfh) seemed to impact the NO and O₂ emissions. The average NO mass emissions were 473 nanograms per joule with a coefficient of variation of 6.7 percent. This represented a 4.3 percent decrease in emissions from the data collected at 0935 to 1025 hours. The O₂ concentration was decreased from 0.4 percent average to 0.3 percent average with a high standard deviation of 0.21. Material temperature was maintained at approximately 1594 K (2410°F) for both the previous test at 143,000 scfh nitrogen and this test at 178,000 scfh nitrogen. A linear regression equation was generated from the data set of kiln exit O₂ and material temperature for the dependent variable nanograms NO as NO₂ per joule. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = 349 + 122.2 \times \% \text{ O}_2 + 0.034 \times \text{Mat. Temp.,} \\ ^\circ\text{F}; r = 0.81)$$

demonstrated that approximately 66 percent of the variation in NO emissions is associated with kiln exit O₂ and material temperature. An average value of 468 ng/joule was calculated from the kiln exit O₂ of 0.3 percent and material temperature of 2410°F.

An attempt is made to quantify any changes in NO emissions data (ng/J) based on the nitrogen injection flow rate changes. The basis for the assessment is a kiln exit O_2 of 0.5 percent and a material temperature of 1611 K (2440°F). These selected values are common for the two time segments considered: 0935 to 1025 hours; 1038 to 1052 hours. NO mass emissions were calculated as 488 ng/J from 0935 to 1025; and 468 ng/J from 1038 to 1052 hours. The percent change is approximately 4.1 percent (from 0935 to 1025 hours to 1038 to 1052 hours).

6.2.5 Nitrogen Injection (198,000 scfh)

A further increase in nitrogen injection rate to 1.58 m³/s (198,000 scfh) was linked timewise with a small reduction of front end temperature along with a significant drop in NO. The time period associated with these data is 1053 to 1107 hours. The average NO emissions were 425 ng/J with a coefficient of variation of 8.9 percent. This represented a 15 percent decrease in emissions from the data collected at 0935 to 1025 hours. The average O_2 concentration was 0.4 percent with a high standard deviation of 0.23 percent. Material temperature was constant at 1597 K (2415°F) during this time increment. A linear regression equation was generated from the data set of kiln exit O_2 and material temperature for the dependent variable nanograms NO as NO₂ per joule. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = -36186 + 127.6 \times \% O_2 + 15.1 \times \text{Mat. Temp.,} \\ ^\circ\text{F; } r = 0.84)$$

demonstrated approximately 71 percent of the variation in NO emissions about the average value of 425 ng/J is associated with kiln exit O_2 and material temperature.

6.2.6 Nitrogen Injection 198,000 scfh), High CO

As the nitrogen injection rate was increasing and the kiln exit O_2 was decreasing, the combustibles concentration (e.g., CO) was becoming more and significant. CO spikes occur during normal operation (no nitrogen injection), apparently due to fluctuations in coal flow rate. These spikes are of very short duration and the lag in sampling and measurement time prevented accurately quantifying the magnitude of the spikes. During the time period of 1117 to 1130 hours, the kiln exit O_2 was about 0.1 percent and the CO spikes increased significantly in frequency and magnitude. Although NO was decreased to less than 355 ppmv corrected to 3 percent O_2 , the prolonged high combustibles level would not be acceptable for continuous operation. The combustibles were observed on the control room strip chart by the operator but the operator had very few options available to decrease the combustibles and maintain the burning zone heat. A change to the ID damper setting (more open) would increase the kiln exit O_2 and lower the combustibles. However, the burning zone would be further elongated compromising material temperature and possibly sending the kiln "into-the-hole." Lowering the fuel rate would also compromise burning zone heat capacity but increase kiln exit O_2 and lower combustibles.

6.2.7 Return to Reference Baseline

The nitrogen injection was stopped at 1130 hours because the liquid nitrogen supply was exhausted. At the time of nitrogen flow termination, a step function increase in NO and O₂ was observed. NO increased from about 350 ppm to about 700 ppm. O₂ increased from 0.1 percent to about 1 percent, and the CO spikes subsided. There was also a sharp increase in coal mill inlet temperature to over 811 K (1000°F), due to transient conditions in the coal mill air supply system, indicating that reduction of N₂ flow should be more gradual.

Eventually, the kiln went into the hole at approximately 1230 to 1300 hours. It is not clear whether the kiln would have gone into the hole if the nitrogen flow rate (1.58 m³/s, 198,000 scfh) had been maintained, or a kiln speed adjustment or other adjustments could have been made to raise the front end temperature. Perhaps, the change in kiln hood draft three hours earlier which clearly decreased O₂ but more importantly changed the burning zone may have been partially responsible for the eventual kiln-in-the-hole condition.

6.2.8 Comparison of Calculated Clinker Rates

A crosscheck of the clinker rates calculated from the weigh belt scale reading, the kiln feeder speed strip chart, and the kiln feeder revs counter was made. Table 19 compares these three calculated clinker rates for November 15th and 17th. The clinker belt scale integrator readings often reflected the combined clinker rate of both kilns, rather than test kiln only. The test kiln clinker rate (from the weigh belt scale) was significantly lower on occasion than the rate calculated from the kiln feeder speed (57 to 58 tons/hours).

The data indicate that the clinker rate calculated from the kiln feeder speed was higher than that measured by the weigh belt scale. There may have been a kiln feed problem with the constant head feeder resulting in less feed entering the kiln than expected.

6.2.9 Results Summary

After the testing was completed, free lime analyses and X-ray diffraction were conducted by the host site. The analyses showed free lime to be acceptable under both baseline and nitrogen injection test conditions. Figure 15 shows the time trace of NO and free lime for the November 17 test day. All free limes were less than 0.4 percent during the baseline and nitrogen injection testing. The free limes did increase dramatically after nitrogen injection testing was completed. Although the material temperature had decreased approximately 87 K (155°F) from initial reference baseline to the end of nitrogen injection testing, the free lime content of the clinker had remained consistent. The burning zone was cooling down based on lower NO emissions data, but had not cooled significantly to cause clinker quality problems. As mentioned earlier (Section 5.3), the material temperature is a measurement used by the operators as an indicator of a more compact burning zone (higher material temperature) or a more elongated burning zone (lower

TABLE 19. COMPARISON OF CALCULATED CLINKER RATES

NOVEMBER 15TH AND 17TH

Test No.	(1) Kiln Feeder		(2)		(3)		Percent Deviation (2) and (3)
	Clinker Belt Scale	Speed (Strip Chart) RPM	Calculated Clinker Rate	Speed (Revs Counter) RPM	Calculated Clinker Rate		
11/15-1	102.0*	15.2	53.6	14.4	50.8	-5.51	
11/15-3	91.0*	15.3	54.0	14.4	50.8	-6.30	
11/15-4	92.0*	15.3	54.0	14.6	51.5	-4.63	
11/15-5	98.0*	15.3	54.0	14.4	50.8	-5.93	
11/15-6	99.0*	15.3	54.0	14.8	52.2	-3.33	
11/15-7	100.0*	15.4	54.4	14.4	50.8	-7.09	
11/15-8	97.0*	14.3	50.4	13.6	48.0	-5.00	
11/15-9	93.6*	14.7	51.8	14.6	51.5	-0.58	
11/15-10	46.8	15.5	54.7	14.6	51.5	-6.21	
11/15-11	-	15.7	55.4	14.8	52.2	-5.78	
11/15-12	51.6	15.7	55.4	15.4	54.4	-1.81	
11/15-13	56.4	15.4	54.4	15.0	53.0	-2.64	
11/15-18	96.0*	16.1	56.9	15.4	54.4	-4.60	
11/15-20	95.0*	17.5	61.8	17.2	60.7	-1.81	
11/15-21	55.2	16.5	58.3	15.8	55.8	-4.48	
11/15-24	55.2	17.0	60.1	16.4	58.0	-3.62	
11/17-1	-	15.8	55.8	14.2	50.1	-11.25	
11/17-2	-	15.7	55.4	15.8	55.8	+0.63	
11/17-3	52.0	15.5	54.7	14.2	50.1	-9.16	
11/17-4	37.2	16.1	56.8	12.4	43.8	-29.84	
11/17-5	83.0*	16.2	57.2	16.0	56.5	-1.26	
11/17-6	49.0	16.2	57.2	14.8	52.2	-9.46	
11/17-7	73.0*	16.2	57.2	15.0	52.9	-8.01	
11/17-8	44.0	16.6	58.6	14.6	51.5	-13.70	
11/17-9	35.0	15.2	53.6	9.2	32.3	-65.20	

* Test kiln and sister kiln (clinker rate over a 5 minute time interval)

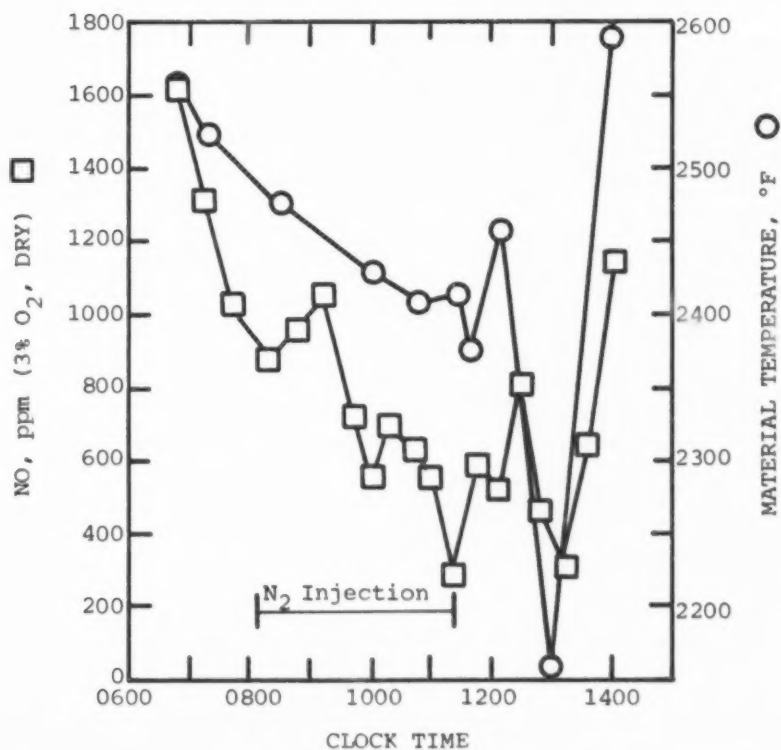
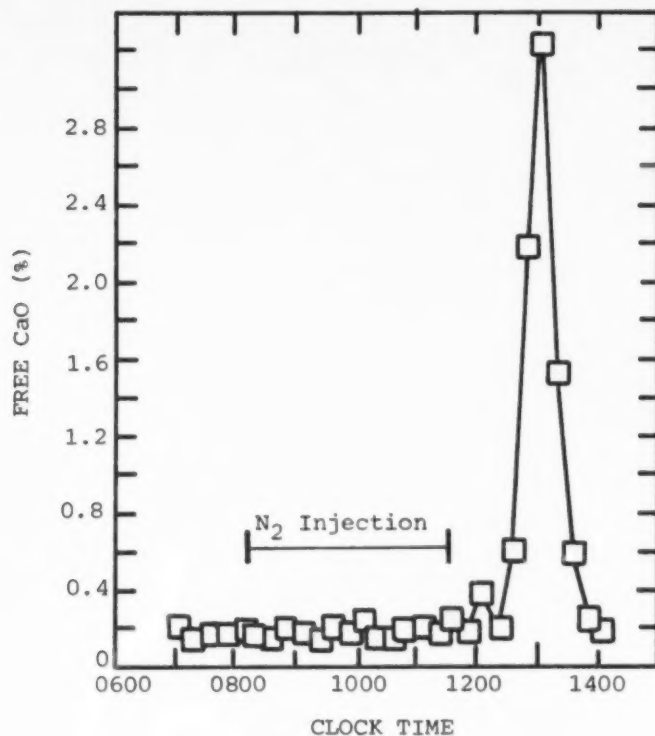


Figure 15. Time Trace of Free Lime, NO and Material Temperature for the November 17, 1983 Nitrogen Injection Test Series

material temperature). The shift in burning zone during the nitrogen injection tests was not evident from measurement of kiln back end temperature and kiln chain temperature. These temperatures did not rise or change appreciably during the nitrogen injection tests.

X-ray diffraction analyses showed some variability of the tricalcium silicate, C_3S over the testing period. This variability was not associated with changes in burning zone temperature as much as normal feed composition changes. Kiln shell temperature was very well-behaved which was another indicator that no sudden changes in feed composition (easy burning to hard burning mix or vice versa) occurred. This was contrary to the events of November 15.

A kiln feed storage silo switch was made at 0600 hours on the morning of November 17. There was approximately a two to two and one half hour time delay between the switch and the new silo feed reaching the burning zone of the kiln. The tricalcium silicate portion of the clinker was approximately 2.5 percentage points higher at 0730 to 0900 hours than 0915 to 1430 hours average. Plant personnel felt this change in C_2S and C_3S proportions did not adversely affect clinker quality and was more indicative of the silo change made earlier in the day.

The conclusions from the November 17th testing were essentially that a specific reduction potential with nitrogen injection could not be identified. The percent reduction between baseline and nitrogen injection was both quite large and quite small depending on the reference baseline data point used (disregarding material temperature and kiln exit O_2 changes). The reduction with nitrogen injection (143,000 scfh) was 26 percent from the initial reference baseline of 981 ng NO as NO_2 per joule. The material temperature decreased 50°F and the kiln exit O_2 decreased approximately 50 percent from baseline conditions. The kiln exit O_2 change was not related to the material temperature change. The percent reduction from final reference baseline, 448 ng NO as NO_2 per joule, compared to nitrogen injection (198,000 scfh) and fairly low combustibles, 425 ng NO as NO_2 per joule, was only 5.1 percent. In this instance, the final reference baseline material temperature was approximately 22 K (39°F) more than nitrogen injection and kiln exit O_2 was approximately 100 percent higher.

Although the NO emission concentration was lowered below the objective of Rule 1112, the combustibles problem rendered the low KVB exit O_2 unsatisfactory under these conditions for long-term plant operation. The events that occurred during nitrogen injection illustrated that NO reduction may be achieved in other ways. The unexpected change in kiln hood draft had an important effect on kiln exit O_2 and material temperature resulting in lower NO_x emissions. Other methods for lowering kiln exit O_2 could include closing down on the ID damper, lowering secondary air temperature and increasing firing rate. While these operational changes are rarely made at the plant, these options do exist for the operator's discretion.

Prior to the last series of nitrogen injection tests (April 17 to 18), a test series was run to evaluate NO emissions reduction by lowering the

kiln exit O_2 with ID damper adjustments (March 1 to 3). This test series would involve incremental drops of the O_2 from a baseline of approximately 2.5 percent to an O_2 where combustibles concentration is unacceptable for kiln operation. Simultaneously, the operator would maintain suitable material temperature and make those operational changes necessary for a steady kiln operation as possible. The information collected from this test series would provide a valuable data base to evaluate emission reduction efficiency between lowered secondary air and lowered primary air O_2 with nitrogen injection (Section 7.0).

A discussion with plant personnel was conducted to devise a test plan which would address the issues raised above. A seemingly desirable approach was to try to maintain a constant O_2 and material temperature with acceptable CO emissions under both baseline and nitrogen injection conditions. Such a plan, however, would not be possible. The rationale is that introducing nitrogen would decrease kiln exit O_2 and material temperature as expected; then kiln exit O_2 would be increased by opening the ID damper or reducing fuel flow. Either choice will compromise burning zone temperature and lead the kiln "into the hole," unless kiln speed is reduced. Rather than a constant O_2 , an overlapping range of kiln exit O_2 's would be investigated. The initial kiln exit O_2 would be nominally 2.5 percent rather a baseline of 1.5 percent for the November 17th tests. The higher O_2 origin would allow nitrogen flow rates up to 225,000 to 250,000 scfh without compromising combustibles. The overlapping data base under baseline and nitrogen injection conditions would provide input for the same types of linear regression equations generated previously. A data base common to both sets of operating conditions would provide a more valid means of evaluating NO reduction potential with nitrogen injection. One of the shortcomings of the November 17th data is that very little overlap of kiln exit O_2 and material temperature data occurred.

6.3 APRIL 17 to 18, 1984

The final nitrogen injection test series was performed for approximately eight hours on April 17th and 18th. The objective of this test was to adjust kiln operating conditions during nitrogen injection so that kiln exit O_2 would remain as constant as possible. A constant O_2 would factor out the effect of O_2 which has complicated the data analysis for previous tests.

The testing can be divided into eight distinct time segments based on testing with and without nitrogen injection and kiln operation changes. These time segments and test descriptions are listed below and discussed in the following sections.

- 4-17 . 1503-1700 -- reference baseline; just prior to nitrogen injection
- . 1715-1755 -- transition from nitrogen shutdown to nitrogen start-up
- . 1901-2050 -- nitrogen injection (201,000 scfh); mill outlet O_2 = 14.1 percent

- 4-17 . 2104-2150 -- nitrogen injection (201,000 scfh); mill outlet O₂ = 13.1 percent, coal flow rate change
- . 2151-2240 -- nitrogen injection (230,000 scfh); mill outlet O₂ = 13.1 percent
- . 2241-2300 -- nitrogen injection (250,000 scfh); mill outlet O₂ = 12.6 percent
- . 2305-2354 -- gradual nitrogen injection shutdown
- 4-18 . 0008-0054 -- return to reference baseline

Table 20 statistically summarizes for each time segment the NO mass emissions along with other key emission data, mill outlet O₂, kiln speed and material temperature. The three statistics reported are the arithmetic mean, sample standard deviation and 95 percent confidence interval. Table 21 summarizes the linear regression analyses for reference baseline and nitrogen injection tests. The dependent process variables chosen are NO (as NO₂) nanograms per joule and NO (as NO₂) pounds per ton of clinker. The NO (as NO₂) nanograms per joule was correlated with material temperature and kiln exit O₂. The other analysis included a correlation of the dependent process variable, pounds NO (as NO₂) per ton of clinker, with the independent process variables; material temperature, clinker rate and kiln exit O₂. The objective of the regression analyses is directed at establishing normalized operating conditions (e.g., same kiln exit O₂ and material temperature) by which NO emissions can be reviewed for baseline and nitrogen injection tests.

6.3.1 Baseline - No Nitrogen

Prior to injecting nitrogen into the primary air stream, two hours of baseline data were collected. Kiln operating changes were minimal as the kiln was operating in a steady mode. Baseline emissions data (1503 to 1700 hours) were recorded approximately two hours prior to nitrogen injection startup. Average baseline emissions were 10.6 pounds NO (as NO₂) per ton of clinker with a standard deviation of 1.63 (Table 20). The coefficient of variation was 15.4 percent which indicated the kiln was operating in a steady operating condition. The kiln exit baseline oxygen averaged approximately 1.4 percent with a standard deviation of 0.5 percent. During this time period, the kiln speed was maintained at a steady 72 rph.

The kiln exit O₂ and material temperature were used to generate a linear regression equation for the dependent process variable, ng NO as NO₂ perjoule. The equation

$$\text{ng NO as NO}_2 \text{ per joule} = -11097 + 140.1 \times \text{kiln exit O}_2, \% + 4.68 \times \text{Mat. Temp, F}; r = 0.71$$

TABLE 20. EMISSIONS DATA SUMMARY
APRIL 17-18, 1984

TIME	NO AS MO2 LBS/TON CLINKER	MO PPM 3X O2	MAT. TEMP. (F)	KILN EXIT O2 %	KILN OUTLET CO2 %	KILN MILL O2 %	KILN SPEED PPH	CO MC/J	KILN EXIT CO PPM	BACHOUSE MO O2 (3X O2)	BACHOUSE CO2 (%)	CLINKER RATE	COAL RATE
(1503 - 1700)	MEAN STD. C195	10.6 1.63 .3	2560 21 4.1	1.4 1.2 .1	31 1.2 .2	21.0 0 0	72 0 0	53 102 20	131 280 51	13.10 .21 .05	1337 146 36	52.1	10.0
(1716 - 1752)	MEAN STD. C195	9.2 1.2 .5	2556 21 7	1.4 .61 .22	31.0 1.24 .45	21.0 0 0	71.0 2.0 .6	71 167 62	175 422 154	13.05 .20 .06	1010 138 44	51.1	10.0
(1901 - 2050)	MEAN STD. C195	8.9 1.5 .3	2557 23 5	.9 .42 .09	28.9 1.4 .3	14.1 .1 0	64.5 2.3 .5	48 143 30	177 376 79	12.77 .15 .03	937 156 33	46.7	10.0
(2104 - 2150)	MEAN STD. C195	11.0 1.5 .5	2556 26 8	2.4 .88 .28	26.0 1.25 .39	13.7 .4 .3	63.0 0 0	15 0 8	36 48 15	13.40 .31 .10	1131 164 55	45.6	9.4
(2158 - 2240)	MEAN STD. C195	7.0 .9 .3	2487 15 5	1.5 .57 .19	27.8 1.4 .44	13.1 .3 .2	62.1 1.4 .4	19 21 7	47 53 17	13.18 .21 .08	644 45 6	44.8	9.6
(2241 - 2300)	MEAN STD. C195	6.7 .9 .4	2468 3 1.4	1.4 .60 .29	28.9 1.5 .46	12.6 0 0	61.0 0 0	83 204 98	216 538 259	13.11 .22 .10	- - -	43.4	9.6
2305 - 2354	MEAN STD. C195	8.5 .7 .2	2518 22 7	2.1 .51 .16	27.6 1.2 .36	16.0 1.5 1.2	66.5 4.7 1.5	14 17 5	33 44 13	13.30 .21 .06	945 92 26	47.6	10.0
0008 - 0054	MEAN STD. C195	8.2 .6 .2	2437 37 11	2.4 .53 .17	29.4 1.2 .38	21.0 0 0	59.5 3.4 1.0	12 2 6	28 5 2	13.33 .06 -	830 17 -	43.0	10.0

*BASED ON KILN FEEDER SPEED
*UNCORRECTED FOR COAL EXTERNAL MOISTURE LOSS

TABLE 21. REGRESSION EQUATIONS FOR THE NITROGEN INJECTION TEST SERIES
APRIL 17-18, 1984

TIME DURATION BEGIN END	NO. OF DATA PTS.	REGRESSION EQUATIONS	CORR. COEF.	STAND. ERR.
1503 1700 (BASELINE)		MC NO(AS NO2) ----- JOULE = -11097 + 140.1 * (KILN EXIT 02, Z) + 4.68 * (MAT. TEMP., F)	.71	118.2
1715 1755 (REFERENCE BASELINE)	31	MC NO(AS NO2) ----- JOULE = -2828 + 162.4 * (KILN EXIT 02, Z) + 1.38 * (MAT. TEMP., F)	.91	50.1
1901 2050 (NITROGEN INJECTION 201,000 SCFH)	90	MC NO(AS NO2) ----- JOULE = 103 + 190.6 * (KILN EXIT 02, Z) + .211 * (MAT. TEMP., F)	.64	95.1
2104 2150 (NITROGEN INJECTION 218,000 SCFH)	42	MC NO(AS NO2) ----- JOULE = -15825 + 66.9 * (KILN EXIT 02, Z) + 6.5 * (MAT. TEMP., F)	.93	57.0
2151 2240 (NITROGEN INJECTION 234,000 SCFH RAISED TO 250,000 SCFH)	39	MC NO(AS NO2) ----- JOULE = 2676 + 94.4 * (KILN EXIT 02, Z) + -.877 * (MAT. TEMP., F)	.88	32.5
2241 2300 (NITROGEN INJECTION 250,000 SCFH)	19	MC NO(AS NO2) ----- JOULE = 224 + 106.8 * (KILN EXIT 02, Z) + .085 * (MAT. TEMP., F)	.85	41.4
2305 2354 (DECREASING NITROGEN INJECTION FLOWRATE)	43	MC NO(AS NO2) ----- JOULE = -5955 + 66.4 * (KILN EXIT 02, Z) + 2.63 * (MAT. TEMP., F)	.92	34.1
0008 0054 (RETURN TO REFERENCE BASELINE)	40	MC NO(AS NO2) ----- JOULE = -1683 + 44.5 * (KILN EXIT 02, Z) + .927 * (MAT. TEMP., F)	.72	37.0

demonstrates that approximately 50 percent of the variation in NO emissions about the average value of 1080 nanograms NO as NO₂ per joule is associated with kiln exit O₂ and material temperatures.

6.3.2 Reference Baseline - No Nitrogen

Just prior to this baseline test, nitrogen was being pumped into the primary air stream. However, this effort had to be temporarily aborted due to pumper problems. After the pumper problems were solved, the baseline testing commenced. Baseline emissions data (1715 to 1755 hours) were recorded for approximately forty minutes prior to the restart of the long term nitrogen injection test program. Average baseline emissions were 9.15 pounds NO (as NO₂) per ton of clinker with a standard deviation of 1.24 (Table 20). The coefficient of variation was 14 percent which indicated the kiln was operating in a steady mode. This steadiness was verified by the material temperature trace (see Appendix F-2). The kiln exit baseline oxygen averaged approximately 1.4 percent with a standard deviation of 0.6 percent. Prior to collecting the baseline emissions data, the kiln operating changes had been minimal for several hours. Kiln speed had been maintained at 72 rph two hours prior to the nitrogen injection.

The kiln exit O₂ and material temperature were used to generate a linear regression equation for the dependent process variable, ng NO as NO₂ per joule. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = -2828 + 162.4 \times \%O_2 + 1.38 \times \text{Mat. temp., } ^\circ\text{F}; \\ r = 0.91)$$

demonstrates that approximately 83 percent of the variation in NO emissions about the average value of 927 ng/J NO (as NO₂) is associated with kiln exit O₂ and material temperature.

Following the reference baseline condition (1756 to 1900 hours), nitrogen was slowly added to the primary stream lowering the mill outlet O₂ from 21 to 14 percent over the course of a fifty minute time period. Average NO and material temperature and kiln exit oxygen were comparable to the reference baseline. This transition will not be reported in detail.

6.3.3 Nitrogen Injection (201,000 scfh)

A steady nitrogen flow rate of 1.60 m³/s (201,000 scfh) was injected into the primary air stream from 1901 to 2050 hours. The average mill outlet oxygen was 14.1 percent with a standard deviation of 0.1 percent. During this time interval the average material temperature 1676K (2557°F) was approximately the same as the reference baseline and nitrogen injection transition to steady state nitrogen injection conditions. A kiln speed change (5 rph slower) at approximately 1930 hours boosted the material temperature along with NO emissions.

Average mass emissions were 8.85 pounds NO as NO₂ per ton of clinker with a standard deviation of 1.49. The NO emissions coefficient of variation was 17 percent indicating that kiln operation was fairly stable over the interval. A 3.3 percent decrease in NO mass emissions from the reference baseline (9.15 to 8.85 pounds NO as NO₂ per ton of clinker) was observed. The kiln exit O₂ decreased approximately to 0.9 percent from an average of 1.4 percent at baseline. Combustibles such as CO were not a problem during this time interval. Average CO emissions were 177 ppm with a 95 percent confidence interval of ± 79 ppm.

The Method 3 calculated pounds NO (as NO₂) per ton of clinker was 9.87 for emissions collected from the multiclone outlet.

6.3.4 Nitrogen Injection (201,000 scfh); Coal Flow Rate Change

This time interval (2104 to 2150 hours) can be differentiated operation wise from the prior test condition by the coal flow rate decrease. Fuel flow was decreased to allow a higher nitrogen injection flow rate later in the evening without lowering the kiln exit O₂ to a point where significant combustibles are observed. The average kiln exit O₂ increased to 2.4 percent during this time period while average material temperature was essentially unchanged. No kiln speed changes were made during this time.

NO emissions increased with the change in kiln exit O₂ and coal flow adjustment. Average NO mass emissions were 10.92 pounds NO as NO₂ per ton of clinker. The increase in NO mass emissions was approximately 4 percent for the increase in kiln exit oxygen from 0.9 to 2.4 percent.

6.3.5 Nitrogen Injection (230,000 scfh)

During this time interval (2158 to 2240 hours), the kiln exit O₂ was decreased from 2.4 percent to 1.5 percent. This decrease was achieved by an increase of coal flow rate (9.4 to 9.6 tons/hour) and the decrease in mill outlet O₂ from 13.7 percent to 13.1 percent. The burning zone temperature shift occurred as the average material temperature decreased from 1675K (2556°F) to 1637K (2487°F).

Average NO mass emissions were 7.0 pounds NO as NO₂ per ton of clinker. The decrease between the NO mass emissions of the previous time period and this time period was approximately 36 percent.

6.3.6 Nitrogen Injection (250,000 scfh)

A further increase in coal flow rate (9.6 to 9.8 tons/hour) and increase in nitrogen flow rate (234,000 to 250,000 scfh) was made at 2240 hours. The overall kiln exit oxygen changed very little (1.5 to 1.4 percent), but material temperature decreased another 20°F. The mill outlet average oxygen was 12.6 percent. A further shift in burning zone temperature occurred but the net effect was a very small change in the NO mass emissions. Average

NO mass emissions were 6.74 pounds NO as NO₂ per ton of clinker. The resultant changes from the previous time interval were a net decrease of 3.2 percent (6.95 to 6.74 pounds NO as NO₂ per ton of clinker).

Since the kiln exit oxygen level of 1.4 percent for this operating condition (mill outlet O₂ = 12.6 percent) is comparable to the baseline kiln exit oxygen (mill outlet O₂ = 20.9 percent), it is apropos to study the effect of N₂ injection on NO reduction for a constant kiln exit oxygen level. Method 2 showed a 34.9 percent decrease from a baseline of 897 nanograms per joule and a 36.8 percent decrease from the baseline of 10.6 pounds NO (as NO₂) per ton of clinker.

6.3.7 Gradual Nitrogen Injection Shutdown

The nitrogen flow rate was gradually decreased stepwise to zero from 2305 to 2354 hours. This gradual decrease was performed to provide a smoother transition for kiln operation with and without nitrogen injection. The average kiln exit oxygen concentration increased, as expected, from 1.4 percent to 2.1 percent and the material temperature increased from 1626 K (2468°F) to 1654 K (2518°F). These increases correlate with the NO mass emissions data. The average NO as NO₂ pounds per ton of clinker increased 27 percent from the value of 6.72 at maximum nitrogen injection.

6.3.8 Return to Reference Baseline

After the nitrogen was completely removed from the primary air stream, a third baseline test was performed for establishing NO reduction potential with nitrogen injection. The kiln exit oxygen increased to an average of 2.4 percent from an average of 2.1 percent prior to nitrogen shutoff. Average material temperature decreased from 1654 K (2518°F) to 1609 K (2437°F) during the second reference baseline condition. The burning zone temperature shift explains the NO mass emissions changes observed.

The third baseline NO as NO₂ pounds per ton of clinker did decrease from the initial baseline figures. The third reference baseline NO mass emissions were 8.18 pounds NO (as NO₂) per ton of clinker. The percentage decrease was 10.6 percent from the initial reference baseline of 9.15 pounds NO (as NO₂) per ton of clinker and 8 percent from the second reference baseline of 8.80 pounds NO (as NO₂) per ton of clinker. The clinker rate had decreased 17 percent from a baseline of 46 tons/hour.

6.3.9 Comparison of Calculated Clinker Rates

Data from the kiln feeder speed strip chart and the kiln feeder revs integrator were gathered to generate clinker rates for each time interval (see Section 4.2 for details). The clinker rate determinations from the feeder revs counter and feeder speed strip chart are shown in Table 22 along with the clinker weigh belt derived clinker rates. The clinker rate calculations for the weigh belt, feeder revs counter and feeder speed strip chart were within a ±15 percent group range for all time intervals.

TABLE 22. CLINKER RATE AND COAL RATE DETERMINATIONS

APRIL 17 - 18

CLINKER RATE DETERMINATION TONS/HR				COAL RATE DETERMINATION TONS/HR	
CLINKER RATES BASED ON :				COAL RATES BASED ON :	
TIME INTERVAL	CLINKER WEIGH BELT SCALE*	FEEDER REVS COUNTER**	KILN FEEDER SPEED**	COAL RATE (UNCORRECTED FOR MOISTURE LOSS BETWEEN SILO AND BURNER END)	COAL RATE (CORRECTED FOR MOISTURE LOSS)
1503 - 1700	52.3	51.5	52.1	10.0	9.5
1715 - 1752	46.0	49.3	51.3	10.0	9.5
1901 - 2050	47.0	46.7	46.7	10.0	9.5
2104 - 2150	44.4	43.7	45.6	9.4	8.9
2158 - 2240	43.2	44.3	44.9	9.6	9.1
2241 - 2259	42.0	40.4	44.1	9.8	9.3
2305 - 2354	42.3	43.8	48.1	10.0	9.5
0008 - 0054	38.5	41.7	43.1	10.0	9.5

*TIME LAG OF 25 MINUTES BETWEEN CLINKER DISCHARGE INTO COOLER
GRATE AND CLINKER WEIGH BELT

**BASED ON 17 FEEDER REVS/TON CLINKER

6.3.10 Raw Mix and Clinker Chemistry/Chemical Composition

The kiln feed analysis results received from the host site show that the average tricalcium silicate, C_3S , on an ignited basis was slightly less for nitrogen injection tests than for the baseline conditions. A burnability factor and burnability index was also calculated for those time intervals when the baseline tests were run and the nitrogen injection tests (see Appendix F). The calculated burnability factor was 113.5 ± 2.6 and burnability index was 3.27 ± 0.41 for the time interval of 1420 to 1630 hours (prior to first baseline). During nitrogen injection tests, the burnability factor was 110.9 ± 1.7 and a burnability index was $3.02 \pm .41$. A second baseline test was run after the nitrogen was shut off. The burnability factor was 109.4 ± 4.8 and burnability index was 2.99 ± 0.64 for the second baseline test. The percent iron oxide and magnesia in the feed increased over the time periods of nitrogen injection and second baseline which in part explains the changes in burnability factor and burnability index. Magnesia and iron oxide act as fluxes which render the burning easier.

The kiln feed burnability factor can be used with the other operational changes to understand the fluctuations in NO emissions and kiln stability. The burnability factor gives consideration to lime saturation factor, silica ratio, and presence of magnesia and alkalis. Figure 16 shows the time trace of NO volumetric emissions (ppm at three percent O_2) and the time corrected kiln feed burnability factor. The kiln feed sample times were adjusted by 90 minutes to correspond to the anticipated arrival of the feed in the burning zone. The figure indicates that as the kiln feed burnability factor begins to stabilize at approximately 109 between 1830 hours and 2030 hours, the NO emissions increase with time from 1000 to 1600 ppm. Based on this burnability factor (lower than baseline burnability factor), the raw mix should be easier to burn and should result in higher NO emissions if no fuel changes, ID damper changes or kiln speed changes are made. It should be noted that the kiln speed was decreased 6 rph at 1925 hours as nitrogen injection was proceeding. The slower kiln speed along with the lower burnability factor would keep the burning zone temperature high and also increase NO emissions. The burnability factor increased 2 to 3 points around 2100 hours and the coal fuel rate was decreased approximately 6 percent from the baseline condition of 10 tons/hour. The burnability change (harder burning mix) and less heat input (coal rate change) would be expected to result in lower NO emissions but an upward trend in the NO emissions was observed (2104 to 2150 hours). Kiln speed slowing at 1925 hours had compensated for the feed and fuel changes. The time interval from 2158 to 2240 hours showed a marked decrease in NO emissions. From an operation standpoint, the kiln speed was decreased 2 rph while fuel flow was increased from 9.4 to 9.6 tons/hour. The feed burnability factor increased slightly during this time. These operation changes should increase burning zone temperature but the opposite occurred. The nitrogen injection into the primary air was beginning to have an effect on the NO emissions level. The maximum nitrogen injection flow rate (2241 to 2300 hours) occurred as kiln speed and feed composition were steady and fuel flow rate was increased from 9.6 to 9.8 tons/hour. NO emissions were at their lowest levels of the test series.

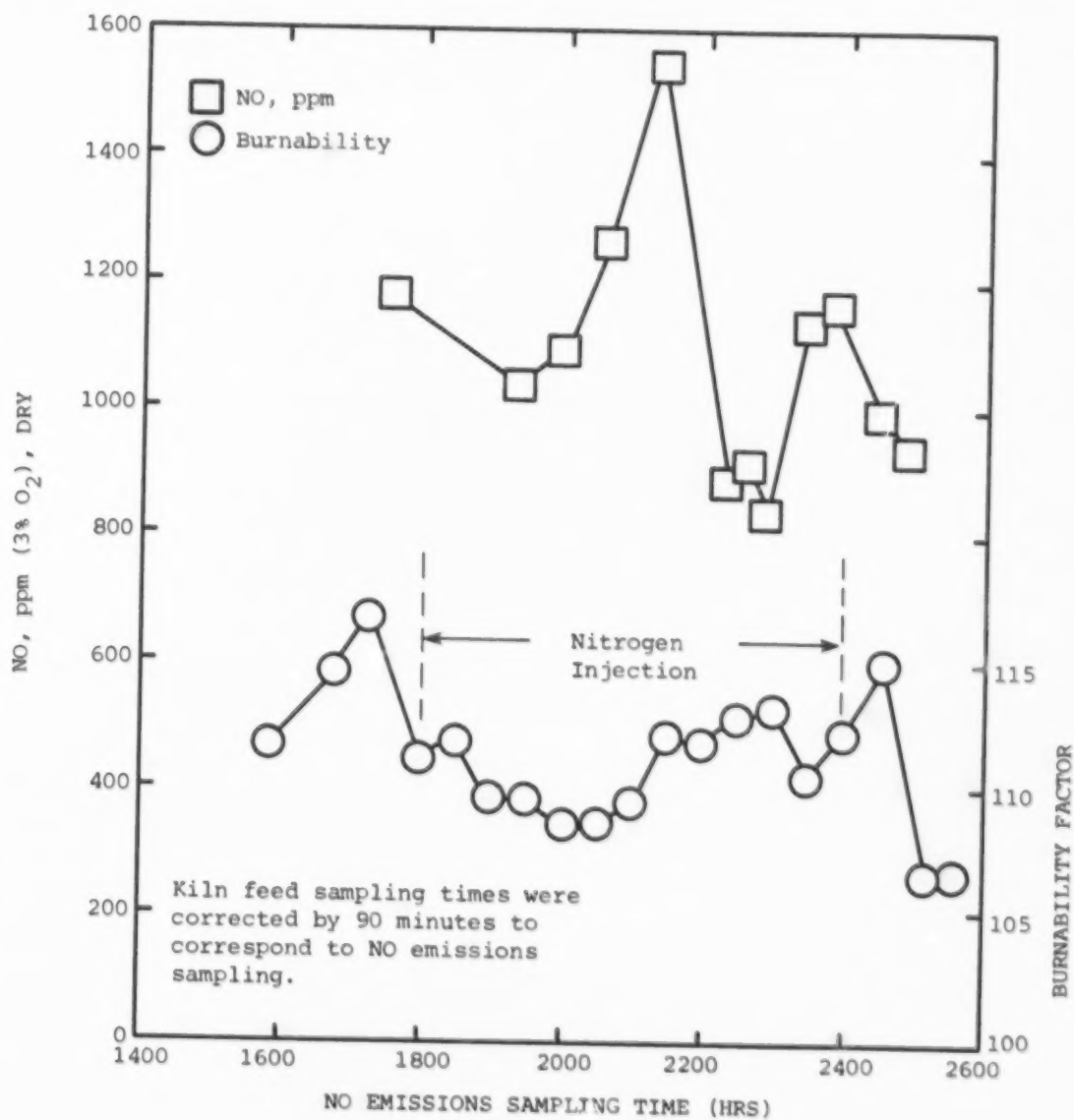


Figure 16. Time Trace of NO Emissions and Corresponding Mix Chemistry/Burnability

The fuel flow steadied at 2300 hours and the kiln feed burnability changed (easier burning feed) at the same time that the nitrogen was being gradually removed from the primary air stream. NO emissions increased from 2305 to 2354 hours reflective of a burning zone change due to the nitrogen removal and an increase in the burnability factor.

The clinker samples were analyzed for compound composition and free lime analysis. Average tricalcium silicate of the clinker sampled during baseline (1335 to 1800 hours) was 60.3 ± 1.9 percent while the average tricalcium silicate of the clinker sampled during the nitrogen injection tests was 58.1 ± 4.2 percent. The alkali content of the clinker was less than 0.6 percent for all samples collected during the first baseline and nitrogen injection tests. The lower average tricalcium silicate value observed with the clinker samples is consistent with that value calculated from the kiln feed (ignited basis). Only two clinker samples were collected following the nitrogen injection shutoff. The tricalcium silicate percent was 54.6 for the second baseline test which is consistent with the time corrected kiln feed samples.

The free lime content of all clinker samples during this test series was less than 0.3 percent indicating that the clinker was well within free lime specifications. The overburning was not unexpected based on the material temperature range observed during the testing. Figure 17 shows the time trace of free lime and NO versus time.

Dr. Ono, a Japanese chemist, has shown that four parameters can be used to evaluate cement quality. These four parameters include C_3S (tricalcium silicate/alite) crystal size, C_2S (dicalcium silicate/belite) crystal size, birefringence of C_3S and C_2S (dicalcium silicate) color (depends on cooling rate). The crystal structures of C_3S and C_2S are a function of the temperature profile. C_2S crystal size depends on the length of the burning zone (the length of kiln in which liquid is present). The liquid is present in heating above 1523 K and in cooling above 1523 K or to the end of the kiln if the clinker is above 1523K as it falls out of the kiln. C_3S crystal size normally depends on the heat rise between 1373 K and 1573 K, but this may change depending on the presence of dissolved salts acting as mineralizers.

"Ono" evaluations were conducted on four ground clinker samples during the April 17 to 18 nitrogen injection test series. The four samples analyzed were C-174 (baseline) sampled at 1700 hours, C-181 (nitrogen injection rate of 201,000 scfh) sampled at 2030 hours, C-185 (nitrogen injection rate of 230,000 scfh) sampled at 2230 hours, and C-191 (return to baseline) sampled at 0053 hours. Alite size range (40 to 60 microns) was rated consistently "poor" over the test period and alite birefringence (0.0057 to 0.0064) was "fair to good" for all four samples. This result is not unexpected based on the consistently high material temperature (2400 to 2600°F) for the test series. The belite size range (20 to 35 microns) was rated as "good to excellent." The cooling rate was rated "fair to good" as indicated by belite color. The conclusion inferred from the "Ono" ground clinker evaluation is that clinker quality did not significantly change during the nitrogen injection test series. Free lime was maintained between 0.1 to 0.3 percent for the two clinker samples

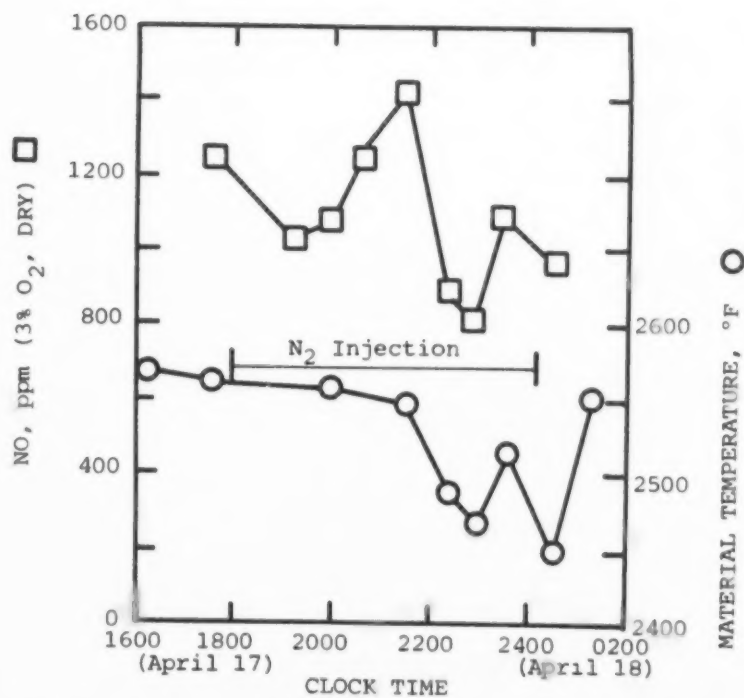
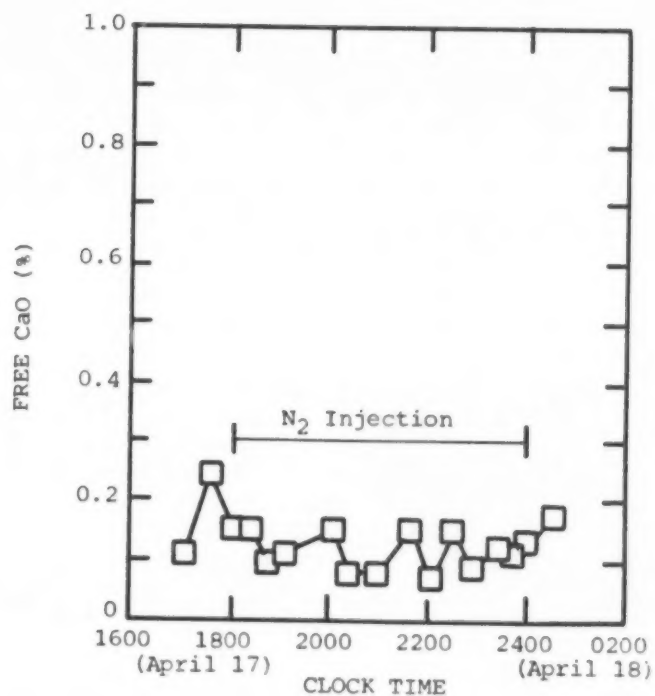


Figure 17. Time Trace of Free Lime, NO and Material Temperature for April 17-18, 1984 Nitrogen Injection Test Series

collected during the nitrogen injection test series. Free lime was maintained between 0.4 to 0.5 percent for the two clinker samples collected during the baseline testing (see Appendix F-1). All of the clinker samples contain practically no sulfur.

The nitrogen content of the raw feed samples (F-94, F-98, F-101, F-104 and F-108) varied over a relatively small range approximately 1 ppm N) with a mean value of 19.2 ppm. Appendix F-1 identifies the raw feed samples collected during the nitrogen injection test series. Particle size distributions, as determined by the sieving of both the "as is" and "acid washed" feeds varied considerably but the significance of the variations is questionable based on the small sample quantity available for analysis.

6.3.11 Determination of NO Emissions Reduction with Primary Air Vitiation

The kiln exit O₂, mill outlet O₂ and material temperature data were used to generate a multiple linear regression equation for the dependent process variable, nanograms NO as NO₂ per joule. The equation (based on the data from Table 20) is applicable to both the baseline and nitrogen injection data. The equation

$$(\text{ng NO as NO}_2 \text{ per joule} = -8489.1 + 3.524 \times \text{Mat. Temp., } ^\circ\text{F}, \\ + 121.8 \times \text{Kiln Exit O}_2, \% + 13.90 \times \text{Mill Exit O}_2, \%; r = 0.96)$$

demonstrates that 91 percent of the variation in NO emissions is associated with material temperature, kiln exit O₂ and mill exit O₂. Using previous baseline and nitrogen data,

	<u>Baseline</u>	<u>N₂ Injection</u>
Material Temperature, °F	2550	2490
Kiln Exit O ₂ , %	1.5	1.5
Mill Exit O ₂ , %	21	13

the nanograms NO as NO₂ per joule is 972 at baseline conditions and 649 at nitrogen injection conditions. The resultant reduction is 33.2 percent based on the data input.

The kiln exit O₂, mill outlet O₂, material temperature and clinker rate were also used to generate a multiple linear regression equation for the dependent process variable, pounds NO as NO₂ per ton of clinker. The equation is applicable to both the baseline and nitrogen injection data. The equation

$$(\text{pounds NO as NO}_2 \text{ per ton of clinker} = -83.86 + 1.09 \times \text{Kiln Exit O}_2, \% \\ + 0.199 \times \text{Mill Exit O}_2, \% + 0.039 \times \text{Mat. Temp., } ^\circ\text{F} - 0.231 \\ \times \text{Clinker Rate, tons/hour; } r = 0.96)$$

demonstrates that approximately 91 percent of the variation in NO emissions is associated with kiln exit O₂, mill outlet O₂, material temperature and clinker rate. Using previous baseline and nitrogen injection data (shown below), the pounds NO as NO₂ per ton of clinker

	<u>Baseline</u>	<u>N₂ Injection</u>
Material Temperature, °F	2550	2490
Kiln Exit O ₂ , %	1.5	1.5
Mill Exit O ₂ , %	21	13
Clinker Rate	46	42

is 10.55 at baseline conditions and is 7.77 at nitrogen injection rates of approximately 230,000 scfh. The percent NO reduction from the baseline condition is approximately 27 percent on a pounds NO as NO₂ per ton of clinker basis.

The results summary show that the Method 2 percent reduction on a NO as NO₂ nanogram per joule is very comparable to the percent reduction on a pounds NO as NO₂ per ton of clinker basis (33 versus 26).

6.3.12 Statistical Analysis of Primary Air Vitiation

As previously described in Sections 6.2 and 6.3, multiple linear regression equations were formulated to model the dependent process variable; whether it be NO (as NO₂) nanograms per joule or NO (as NO₂) pounds per ton of clinker. The purpose of the regression equations was to use a limited set of independent process variables which might aptly predict the observed NO mass emissions values. The dependent process variable, NO (as NO₂) nanograms per joule, was described by the kiln exit O₂ and material temperature. The dependent process variable, NO (as NO₂) pounds per ton of clinker was modelled by kiln exit O₂, material temperature and clinker rate. On most occasions, the NO data in a particular time segment of baseline or nitrogen injection was aptly described by the independent process variables used. The r-square (r²) represents the fraction of the variability in the response variable (dependent variable) which has been accounted for in terms of the variability of the predictor variables in the model. Typically, r-square values greater than 70 percent represent a good fit.

From Section 6.3.11, it has already been demonstrated that with the addition of mill exit O₂ to the set of independent process variables, the accountability of variation in actual NO mass emissions is approximately 91 percent (r-square value) for the April 17 to 18, 1984 nitrogen injection series. The predicted NO emissions from the baseline conditions are approximately 30 percent lower based on the multiple linear regression equation. The

basis for this number is the lower material temperature (2550°F to 2490°F) and decrease in the clinker rate (46 to 42 tons/hr) with a decrease in mill exit O₂ (21 to 13 percent).

After these analyses were completed, the question remained of how much effect does the one percent decrease in mill exit O₂ have on NO emissions, holding all other operational parameters constant. A statistician familiar with systems modeling was retained to help answer this question. His report is included in Appendix H. A summary of his work is discussed below. The first task was to model the behavior of the dynamic kiln system operation with a set of simultaneous equations. Six structural equations were devised as model fits for kiln exit NO (ppmV), kiln exit O₂ (percent), rotation speed (rph); material temperature (°F), kiln exit CO (ppmV), and kiln exit CO₂ (percent). The final structural equations both fit and forecast very well for NO, rotation speed and material but only an adequate job for O₂ and CO₂. The final structural equation for NO was modelled with the mill outlet O₂, kiln exit O₂, burnability factor moving average, kiln speed, coal rate and ID damper setting.

Two data sets were derived from the April 17 to 18 nitrogen injection test series for the purposes of determining the effect of mill outlet O₂ on NO emissions. The data sets are identified as MOD(6)=2 and MOD(6)=4 beginning at 1604 hours and 1606 hours, respectively. MOD(6)=2 has 87 data points with complete observations; however 16 of those data points had to be completed with data from the nearest data neighbor. MOD(6)=4 also has 87 data points with complete observations but 17 of those data points had to be completed with data from the nearest data neighbor.

A summary table of the volumetric NO ppm reduction statistically expected with mill outlet oxygen decrease is reported in Table 23. The reductions are based on holding constant certain variables in the NO model. If the burning zone temperature, burnability factor, rotation speed and coal rate were held constant, then the effect of lowering mill outlet O₂ one percentage point is estimated to be 51.4 ppm NO (standard error of 9.4 ppm). The experimental range is 12.5 to 21.0 percent O₂. This reduction is specific to the MOD(6)=2 data set. An asymptotic t-test of the null hypothesis that changing mill outlet O₂ under these controlled conditions has no effect on NO indicates that the estimate is significantly different from zero at the 0.0001 level (P < 0.0001).

The data show that the NO concentration change per one percent change in mill outlet oxygen ranges from 16.4 to 76 ppm NO decrease per one percent mill outlet O₂ decrease. The two data subsets seem to agree fairly well in the NO concentration decreases. The actual effect depends on what is held constant (by the model) and what is not. No check was made for the linearity of this effect.

The structural equations do have limitations which should be acknowledged for results interpretation. More variables should be added to the structural equations to improve the system model. In particular, endogeneous

TABLE 23. STATISTICAL ANALYSIS OF MILL O₂ VARIATION ON KILN NO EMISSIONS

Predictor Variables		Data Set	[NO](as Measured)/[NO](corrected to 3% O ₂)		
Held Constant	Not Held Constant		$\frac{\partial[\text{NO}]}{\partial[\text{Mill O}_2]}$	Standard Error	P value
Temp, Coal, Rotat, MAA	-	MOD(6)=2	51.4/51.5	9.4/11.8	0.0001/0.0001
Temp, Coal, Rotat, MAA	-	MOD(6)=4	41.0/47.6	8.6/9.4	0.0001/0.0001
Coal, Rotat, MAA	Temp	MOD(6)=2	76.0/71.5	11.2/12.4	0.0001/0.0001
Coal, Rotat MAA	Temp	MOD(6)=4	61.4/65.8	10.8/11.0	0.0001/0.0001
Temp, Coal, Rotat	MAA	MOD(6)=2	33.6/34.5	6.1/7.6	0.0001/0.0001
Temp, Coal Rotat	MAA	MOD(6)=4	36.0/42.6	5.9/6.4	0.0001/0.0001
Temp, Coal MAA	Rotat	MOD(6)=2	53.3/57.1	9.2/11.6	0.0001/0.0001
Temp, Coal MAA	Rotat	MOD(6)=4	42.9/49.0	8.5/9.4	0.0001/0.0001
Temp, Rotat MAA	Coal	MOD(6)=2	19.3/19.4	7.3/8.8	0.0098/0.00306
Temp, Rotat MAA	Coal	MOD(6)=4	20.0/18.9	6.9/7.8	0.0047/0.00175
Temp, Coal Rotat, MAA Damp	-	MOD(6)=2	49.7/42.2	13.7/17.1	0.0006/0.0106
Temp, Coal Rotat, MAA Damp	-	MOD(6)=4	35.7/38.1	12.4/13.5	0.0053/0.0061
Temp, Coal Rotat, MAA Exhaust O ₂	-	MOD(6)=2	41.3	11.6	0.0009

Data Sets

MOD(6)=2 4/17 1604 hours starting time; 87 complete observations

MOD(6)=4 4/17 1606 hours starting time; 87 complete observations

Predictor Variables

Temp - material temperature

MAA - burnability factor moving average

Damp - damper setting on the induced draft fan

Coal - coal flow rate

Rotat - kiln rotation speed

Exhaust O₂ - kiln exit oxygen

variables such as the secondary air temperature, kiln hood pressure and undergrate pressure should be added to the NO model for improved forecasting of perturbations in NO emissions.

Another difficulty with associating a specific NO decrease per one percent decrease in mill outlet oxygen is that the other predictor variables are unlikely to remain constant. If the mill outlet O₂ is decreased from 21 to 13 percent oxygen, operational changes are very likely to occur. Kiln speed changes are made to retain the heat requirements in the burning zone while kiln exit oxygen is expected to decrease. Kiln speed changes will affect the undergrate pressure and consequently the kiln hood pressure.

The interpretation of the results should also be weighed against the ad hoc procedure used to fill in the missing values. For future work any observed time series should consist of sequential data points with no discontinuities.

6.3.13 Results Summary

Figure 18 presents the time plot of lb NO₂/ton of clinker and kiln exit O₂, with the values plotted as three-hour rolling averages to smooth the fluctuations. The objective of holding kiln O₂ constant was not completely met but the O₂ was considerably steadier than in previous tests. The period of N₂ injection is shown on the figure. Lb NO₂/ton of clinker was reduced from about 9.6 lb/ton at baseline to about 7.0 lb/ton at the end of injection, a 27 percent reduction. The degree of reduction cannot be attributed entirely to the N₂ injection. Changes in kiln speed, coal flow, material temperature, feed composition, and other variables, in spite of the operator's desire to maintain constant conditions, complicate the data analysis.

High speed motion pictures were taken of the flame near the tip of the burner at 2,000 frames per second. These films and operator observations indicated a definite lengthening and cooling of the flame. This effect is normal for low NO operation on other combustion devices, but would require further investigation over a longer time to determine if this effect could be acceptable for clinker quality and kiln life.

Analysis of raw feed and clinker samples indicate that most of the clinker variability could be explained by feed composition variation. The free lime content throughout this test series was less than 0.3 percent and alkali content remained less than 0.6 percent. It was concluded that the test did not result in deterioration of clinker quality, but it was apparent that the clinker was being overburned, probably due to the kiln operator's concern for avoiding an upset as the result of the test.

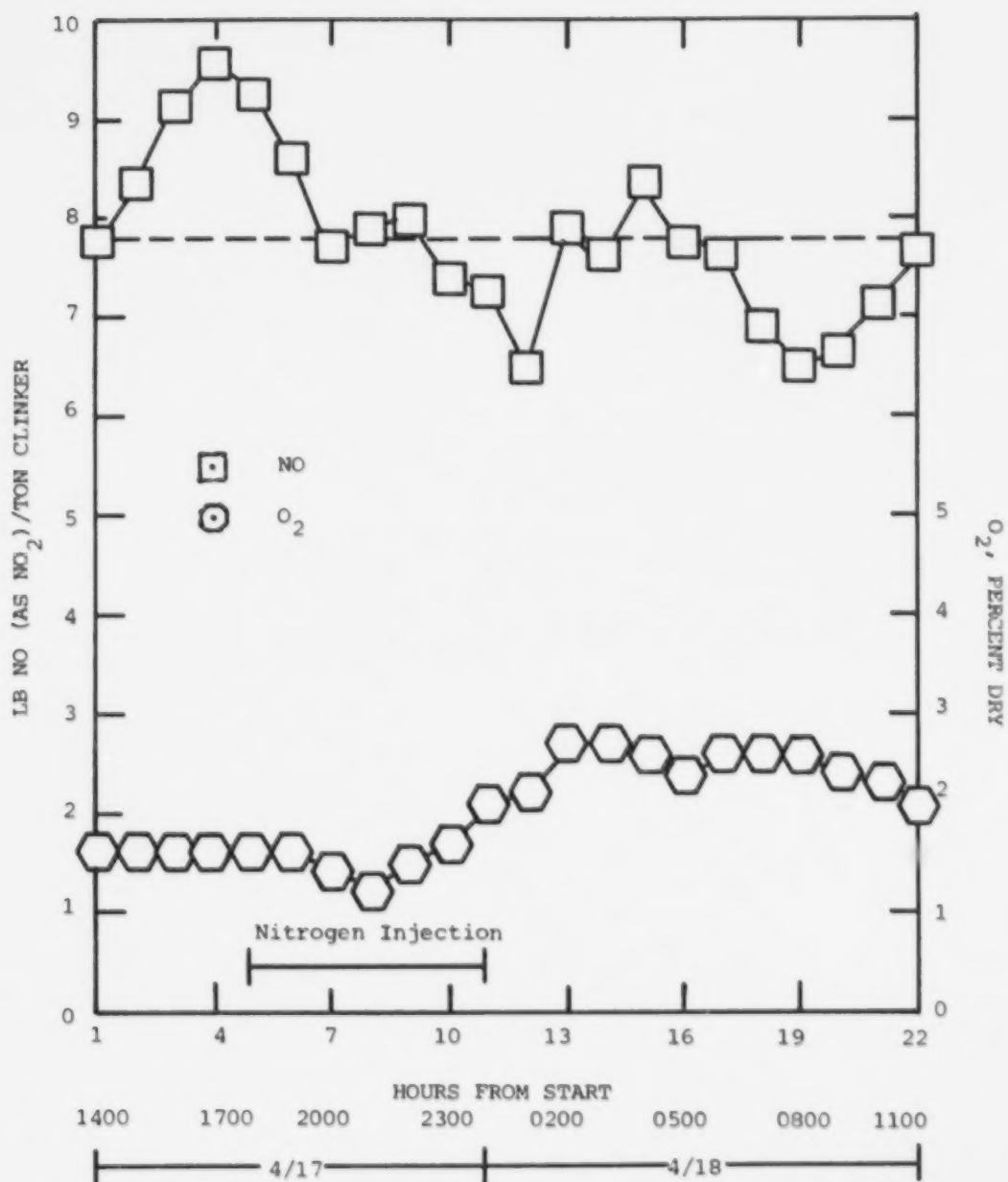


Figure 18. Three-Hour Rolling Average

SECTION 7.0

LOWERED EXCESS AIR TEST SERIES

While nitrogen injection in the primary air stream did achieve some NO reduction, lowering excess air (LEA) with kiln system controls (e.g., closing the ID damper) to reduce NO emissions was still another possibility. The objective of this test series was to determine if a discernible difference in NO reduction is observed between low excess air and nitrogen injection.

Since there had been considerable difficulty acquiring emissions data under fairly steady operating conditions, a decision was made to monitor the kiln operation for a four-day period. The aim of the long-term test was to record data during those time periods when the kiln was operating in a fairly steady mode. During the test, the kiln operator was requested to maintain, if possible, the material temperature over a particular range of 1533 to 1644 K (2300 to 2500°F) for baseline kiln exit oxygen and low kiln exit oxygen levels. This temperature range was selected to match that temperature data recorded during the nitrogen injection tests. Strip charts from the control room are presented in Appendix G-1. Mix chemistry and clinker analyses are shown in Appendix G-2. The mass emissions data on a time basis are shown in Appendix G-3. Only Method Two results are reported here. The clinker rate determinations from the weigh belt scale and kiln feeder speed are included in the mass emissions calculations.

7.1 BASELINE DATA SUMMARY

Table 24 summarizes the baseline emissions and operating data for a material temperature range of 1588 to 1644 K (2400 to 2525°F). This material temperature range was used to compare the data collected during the nitrogen injection tests. A statistical summary of the emissions data (volumetric basis) and operation data (coal rate, material temperature and clinker rate) are presented in terms of the arithmetic mean, standard deviation and 95 percent confidence interval. The data on a mass basis are clinker rate (tons/hr); million Btu per ton of clinker and pounds NO as NO₂ per ton of clinker. The average O₂ for this 6.5 hours of data was 1.82 percent $\pm$ 0.08 (at the 95 percent confidence level) and the average NO concentration was 1050 ppm (corrected to 3 percent) $\pm$ 55 ppm (at the 95 percent confidence level). The mean material temperature was 2460°F $\pm$ 14°F (at the 95 percent confidence level).

Table 25 shows the clinker rate, the thermal heat input per ton of clinker (MMBtu/ton clinker) and the pounds NO (as NO₂) per ton of clinker. The time weighted average lb NO (as NO₂) per ton of clinker for the as-found data based on clinker weigh belt scale is 8.07 (4.13 g NO₂/kg clinker). Conversely, the lb NO (as NO₂) per ton of clinker based on the kiln speed derived clinker rate is 7.21 (3.69 g NO₂/kg clinker).

TABLE 24. BASELINE DATA SUMMARY - LEA TEST SERIES

Test Condition: Lowered Excess Air
 Material Temperature Range: 2400-2525°F
 N₂ Flow Rate (scfh): None
 Coal Heat Value: 12,260 Btu/lb

Day	Time	O ₂ vol %	CO ₂ vol %	CO ppmv	NO ppmv, 3% O ₂	Coal* Rate (tons/hr)	Mat. Temp. (°F)	Measured Clinker Rate (tons/hr)
2/29	1152-1206	1.7	30.1	32	1315.1	9.07	2512	55.4
	1207;	1.9	29.6	30	1354.1	9.07	2525	55.4
	1212-1225	2.0	29.5	39	1315.7	9.07	2525	55.4
	1226-1240	1.8	31.0	197	1085.6	9.07	2500	55.4
	1241-1255	1.8	30.4	188	973.5	9.07	2437	55.4
	1256-1310	1.8	30.5	79	901.3	9.07	2425	55.4
	1311;	2.0	29.6	67	902.4	9.07	2400	55.4
	1318-1331	2.1	28.9	200	1008.5	9.07	2450	55.4
	1332-1346	2.2	28.9	42	1082.5	9.07	2500	55.4
	1347-1401	2.2	29.6	284	997.1	9.07	2450	55.4
	1402-1416							
	1417-1440							
3/1	2114-2128	1.9	27.7	111	880.0	8.82	2437	42.5
	2129-2147	1.8	28.8	52	899.0	8.82	2450	42.5
3/3	0046-0100	1.8	29.7	28	1099.0	9.08	2500	43.2
	0101-0115	1.7	30.1	69	996.3	9.08	2450	43.2
	0116-0130	1.6	30.3	205	815.9	9.08	2400	48.7
	0131-0145	1.5	29.7	164	988.3	9.08	2437	48.7
	0218-0232	1.6	29.9	38	1230.5	9.08	2500	42.7
	0606-0620	1.8	29.2	33	1000.3	9.08	2425	45.0
	0621-0635	2.0	28.3	27	1012.0	9.08	2437	45.0
	0636-0658	2.0	28.5	59	1078.0	9.08	2450	45.0
	0659-0713	1.8	29.0	28	1113.5	9.08	2475	45.0
	0714-0728	1.7	29.5	161	1063.1	9.08	2462	45.0
	0729-0743	1.8	29.4	29	1065.0	9.08	2462	45.0
	0744-0804	1.5	30.7	42	899.5	9.08	2425	45.0
	0835-0859	1.7	28.9	27	1067.2	9.08	2462	45.0
	0900-0914	1.6	29.8	48	1161.8	9.08	2475	45.0
		1.82	29.5	88	1050.0	9.08	2460	48.9
	σ	0.2	0.8	75	138.0	0.09	35	5.5
	CI95	0.08	0.3	30	55.0	0.04	14	2.2
	CV (%)	11.0	2.7	85	13.1	0.9	14	11.2

*Corrected for moisture loss through the coal mill.

TABLE 25. COMPARISON OF METHOD TWO MASS EMISSIONS USING
KILN SPEED AND CLINKER WEIGH BELT SCALE

Date 1984	Time		Clinker Rate (Ton/Hr)				MMBtu/Ton Clinker				Lbs NO/Ton Clinker			
	Begin	End	Kiln Speed	Weigh Belt	% Dev		Kiln Speed	Weigh Belt	% Dev		Kiln Speed	Weigh Belt	% Dev	
2/29	1152	1440	57.01	55.44	2.8		3.91	4.02	2.8		6.72	7.55	11.0	
3/1	2114	2147	52.5	42.5	19.0		4.13	5.09	23.5		6.28	7.44	15.6	
3/3	0046	0914	51.3	45.11	12.1		4.37	4.71	8.5		7.69	8.53		
Baseline Avg			53.6	48.7	9.1		4.17	4.61	9.5		7.21	8.07	10.7	
3/2	1533	1602	50.3	43.6	13.3		4.42	5.10	13.3		6.51	7.3	10.8	
3/3	1826	2248	56.3	46.7	17.1		3.9	4.71	17.2		6.00	6.97	13.9	
LEA Avg			55.4	46.5	16.1		3.98	4.77	16.6		6.08	7.02	13.4	

7.2 LOW EXCESS AIR DATA SUMMARY

Table 26 summarizes the low excess air emissions and operating data for a material temperature range of 2400 to 2525°F. A statistical summary of the emissions data (volumetric basis) and operations data (coal rate, material temperature and clinker rate) are presented in terms of the arithmetic mean, standard deviation and 95 percent confidence interval. The data on a mass basis are clinker rate (tons/hr); million Btu per ton of clinker and pounds NO as NO₂ per ton of clinker. The average O₂ kiln exit percent for this 3.25 hours of data was 0.71 ± 0.23 (at the 95 percent confidence level) and the average NO concentration was 880 ppm $\pm$ 85 ppm (at the 95 percent confidence level). The mean material temperature was 2477°F $\pm$ 35°F (at the 95 percent confidence interval).

The baseline and low excess air data are plotted for a series of temperature ranges. Figures 19 and 20 shows NO versus kiln exit oxygen for a material temperature range of 2500 $\pm$ 25°F and 2450 $\pm$ 25°F, respectively. Figure 21 combines the data from Figures 19 and 20. The data show that for the kiln exit oxygen range tested, the NO emissions can vary up to 300 to 400 ppm for a given kiln exit oxygen level.

Since the average material temperature for both the baseline and low excess air test series was approximately the same, the percent NO reduction due to O₂ variation can be assessed more easily. The percent NO reduction (volumetric basis) due to low excess air is approximately 20 percent for the operating conditions described above. Some of the 15 minute averages were lower than the average O₂, as low as 0.4 percent, which would show a greater percent NO reduction (probably as much as 30 percent). The operational reality at these lower kiln exit oxygen levels is that the combustibles are high and unacceptable for continuous operation. Figure 22 shows the CO concentration (as measured) versus the kiln exit O₂. The curve shows the pronounced effect on CO emissions by lowering the kiln exit O₂ below 1 percent. Based on this curve, the kiln exit O₂ of 0.7 percent is probably the reasonable low O₂ level for the CO limit.

Table 25 shows the percent deviation for each time period along with average percent deviation for the entire test series. The time weighted average lb NO (as NO₂) per ton of clinker based on the clinker weigh belt scale is 7.02 (3.51 g NO₂/kg clinker). Conversely, the lb NO (as NO₂) per ton of clinker based on the kiln speed derived clinker rate is 6.08 (3.04 g NO₂/kg clinker).

7.3 DETERMINATION OF NO EMISSIONS REDUCTION WITH LOW EXCESS AIR

The kiln exit O₂ and material temperature were used to generate multiple linear regression equations for the dependent process variable, ng NO as NO₂ per joule for baseline and low excess air conditions. Table 27 shows these equations with the correlation coefficient and standard error for each.

TABLE 26. LOW EXCESS AIR DATA SUMMARY

Test Condition: Lowered Excess Air
 Material Temperature Range: 2400-2525°F
 N₂ Flow Rate (scfh): None
 Coal Heat Value: 12,260 Btu/lb

Day	Time	O ₂ vol %	CO ₂ vol %	CO ppmv	NO ppmv, 3% O ₂	Coal* Rate (tons/hr)	Mat. Temp. (°F)	Measured Clinker Rate (tons/hr)
3/2	1533-1547	1.3	29.9	30	885.7	9.05	2462	43.5
	1548-1602	1.4	29.9	30	860.7	9.05	2450	43.6
3/3	1826-1838	0.95	31.5	280	929.0	8.95	2462	45.0
	1839-1853	0.8	31.6	278	975.0	8.95	2512	45.0
	1854-1908	0.8	31.8	242	1032.0	8.95	2512	45.0
	1909-1923	0.7	33.0	246	915.0	8.95	2500	45.0
	1924-1942	0.5	33.1	776	725.0	8.95	2487	45.0
	1943-1957	0.4	34.2	841	599.0	8.95	2450	45.0
	1958-2012	0.4	31.9	582	750.0	8.95	2400	45.0
	2013-2027	0.4	31.4	426	986.0	8.95	2500	45.0
	2116-2146	0.6	33.9	412	794.0	8.95	2437	54.6
	2212-2223	1.0	30.4	124	1081.0	8.95	2500	49.5
	2234-2248	0.9	32.3	347	998.0	8.95	2525	49.5
		0.71	31.9	355	880.0	9.00	2477	46.2
	σ	0.37	1.4	254	141.0	0.04	36	3.1
	CI95	0.23	0.6	103	85.0	0.01	15	1.3
	CV (%)	52.1	4.3	71.6	16.0	0.45	1.5	6.8

*Corrected for moisture loss through the coal mill.

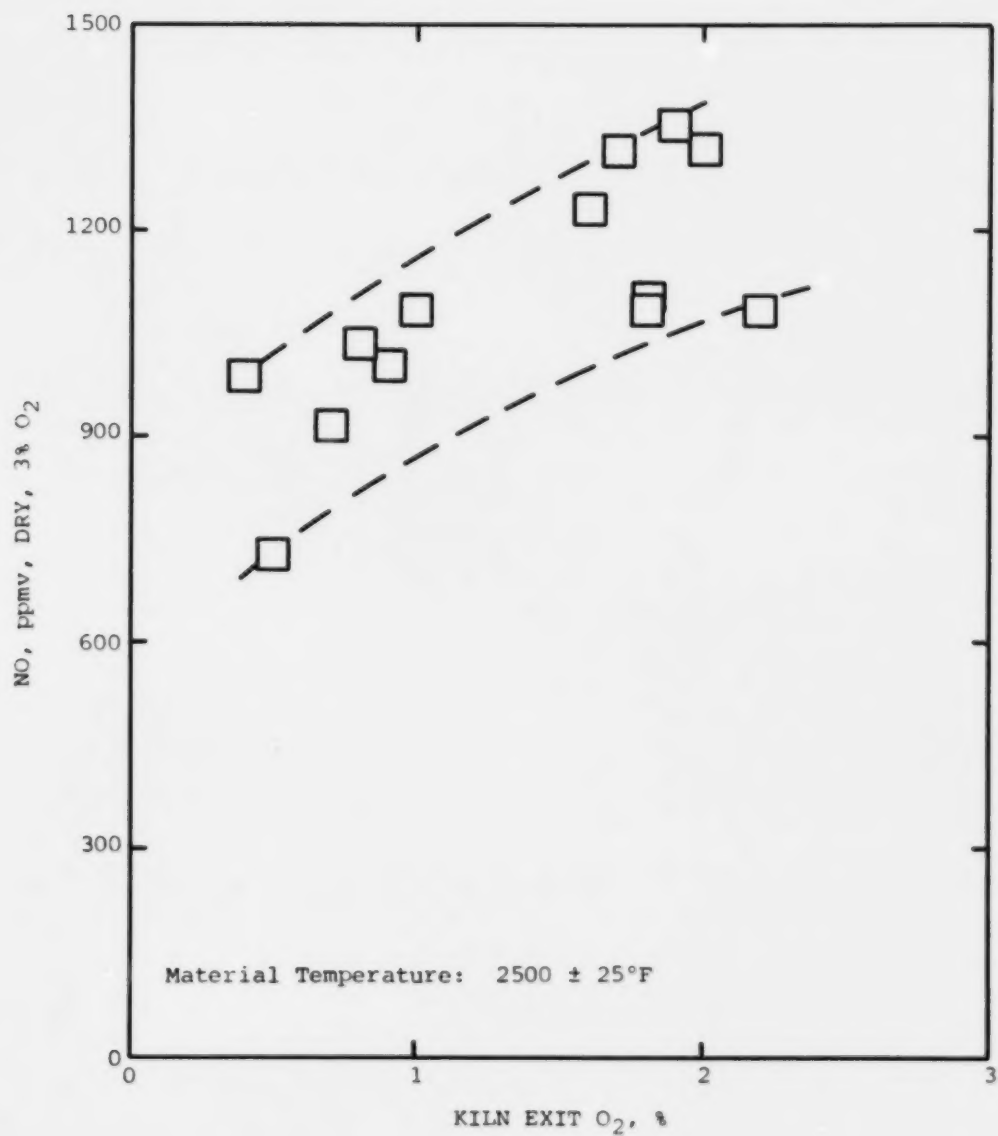


Figure 19. NO versus O₂ (Material Temperature Range of 2500 ± 25°F)

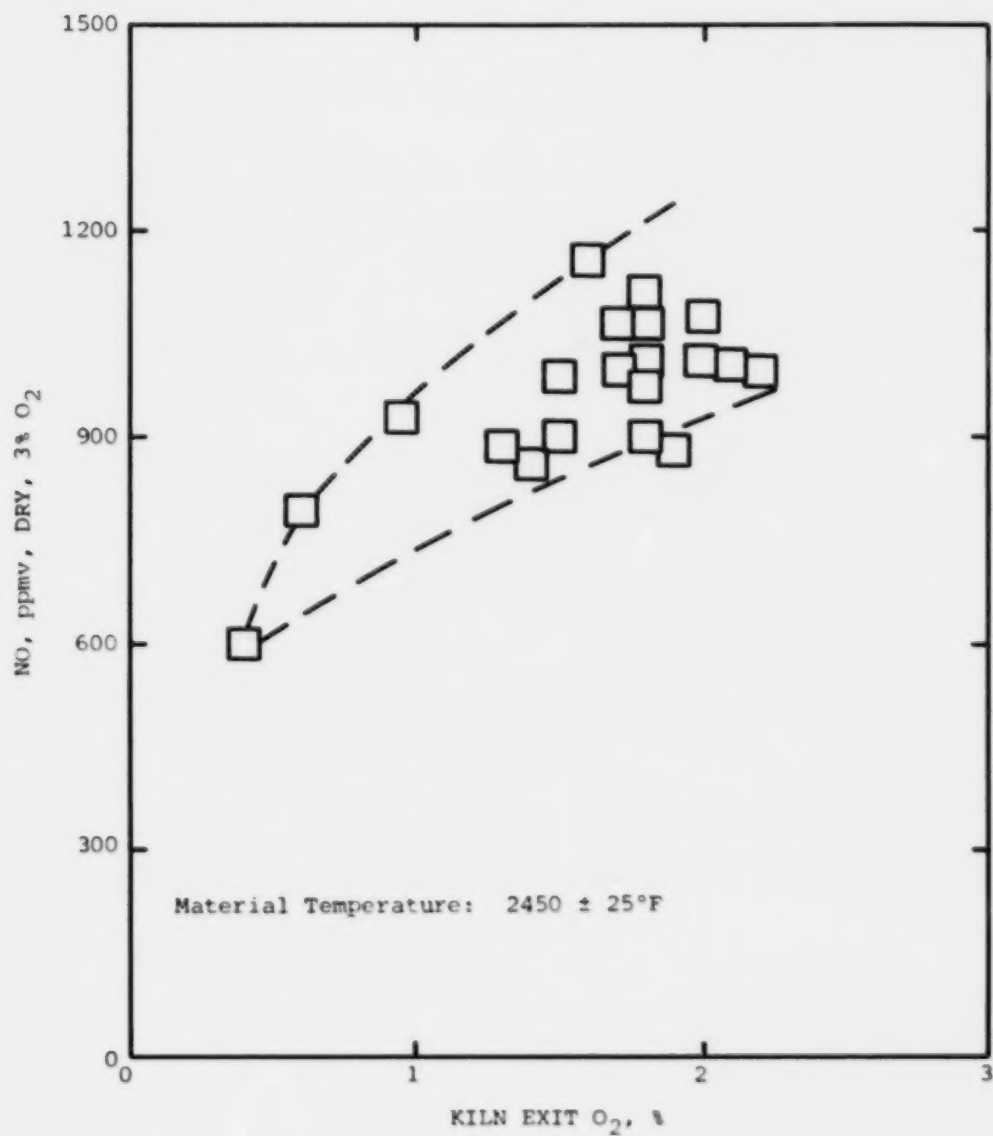


Figure 20. NO versus O_2 (Material Temperature Range of $2450 \pm 25^\circ F$)

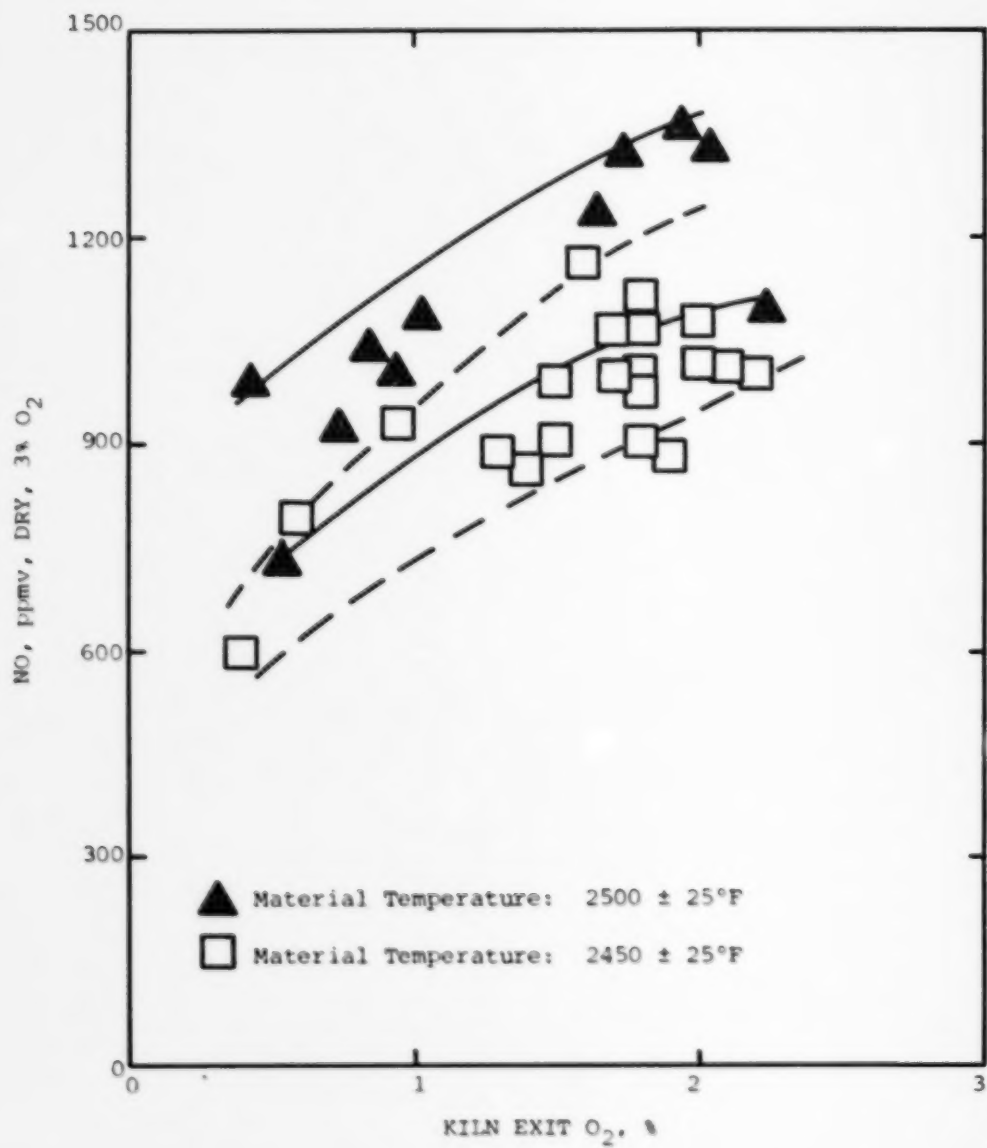


Figure 21. NO versus O_2 (Material Temperature Range of 2425 - $2525^\circ F$)

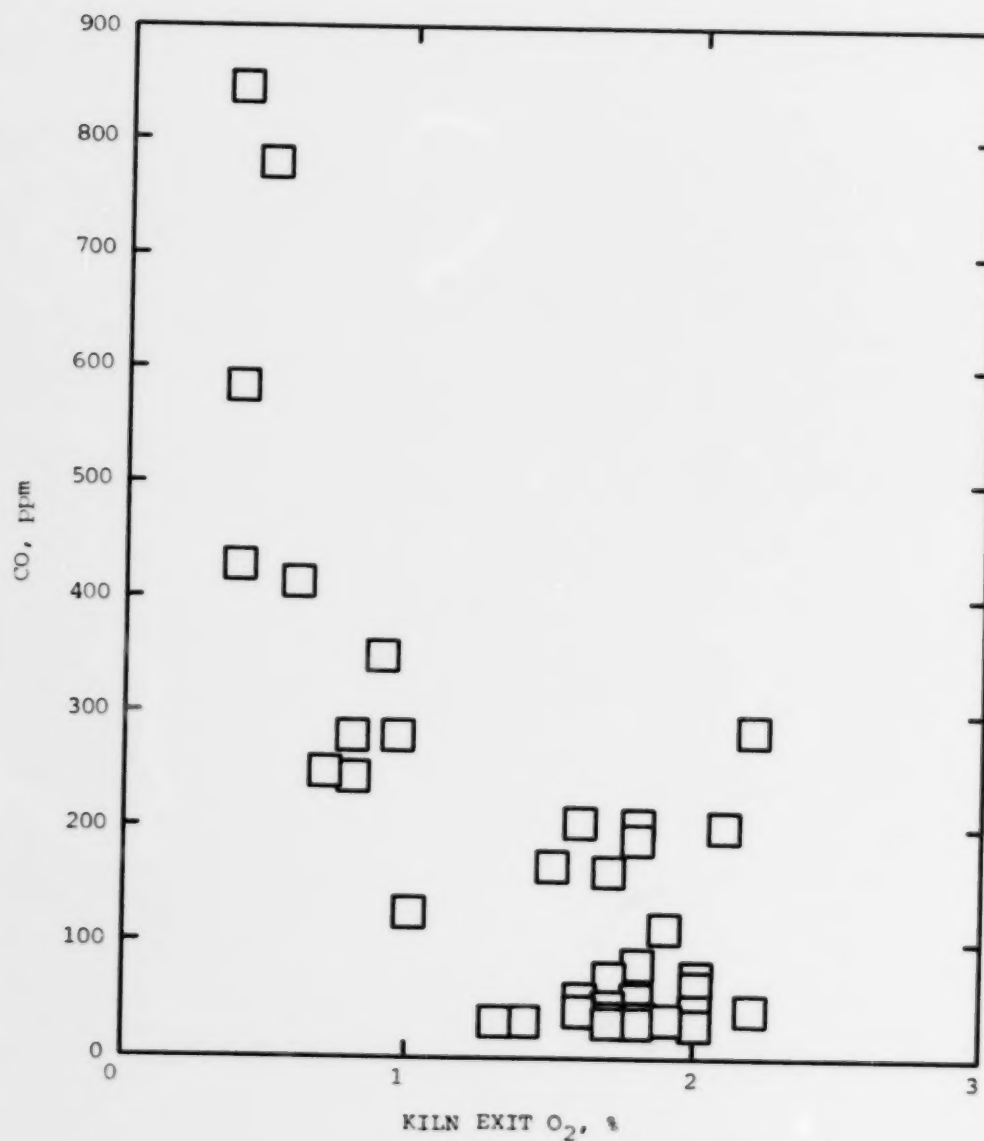


Figure 22. CO versus O₂

TABLE 27. REGRESSION EQUATIONS FOR THE LEA TEST SERIES TO DETERMINE
NO (AS NO₂) NANOGRAMS PER JOULE
FEBRUARY 29 - MARCH 3, 1984

CONDITION	NO. OF DATA POINTS (HRS)	METHOD	REGRESSION EQUATIONS	CORR. COEF.	STAND. ERR.
BASELINE	26 (6.5)	2	$\text{NO (AS NO}_2\text{)} = -5964 - 3.4 * (\text{KILN EXIT O}_2, \%) + 2.74 * (\text{MAT. TEMP., } ^\circ\text{F})$ JOULE	.91	45.8
LOWER EXCESS AIR	13 (3.3)	2	$\text{NO (AS NO}_2\text{)} = -4239 + 96.9 * (\text{KILN EXIT O}_2, \%) + 1.95 * (\text{MAT. TEMP., } ^\circ\text{F})$ JOULE	.77	73.3
BASELINE AND LOWER EXCESS AIR	39 (9.8)	2	$\text{NO (AS NO}_2\text{)} = -5248 + 129 * (\text{KILN EXIT O}_2, \%) + 2.35 * (\text{MAT. TEMP., } ^\circ\text{F})$ JOULE	.87	59.6

The equation for reference baseline conditions,

$$\begin{aligned} (\text{ng NO as NO}_2 \text{ per joule} = & -5964 - 3.4 \times \text{Kiln Exit O}_2, \% \\ & + 2.74 \times \text{Mat. Temp., } ^\circ\text{F}; r = 0.91) \end{aligned}$$

demonstrates that approximately 82 percent of the variation in NO emissions about the average value of 770 ng/J NO (as NO₂) is associated with kiln exit O₂ and material temperature. The equation for low excess air conditions,

$$\begin{aligned} (\text{ng NO as NO}_2 \text{ per joule} = & -4239 + 96.9 \times \text{Kiln Exit O}_2, \% \\ & + 1.95 \times \text{Mat. Temp., } ^\circ\text{F}; r = 0.77) \end{aligned}$$

demonstrates that approximately 60 percent of the variation in NO emissions about the average value of 660 ng/J NO (as NO₂) is associated with kiln exit O₂ and material temperature.

The kiln exit O₂ and material temperature data were then used to generate a multiple linear regression equation for the dependent process variable (nanograms NO as NO₂ per joule) for both the baseline and low excess air data. The 39 data points from the baseline and low excess air data were the basis for the equation stated in Table 27. The Method 2 equation demonstrated that 76 percent of the NO mass emissions (ng NO as NO₂ per joule) is associated with material temperature and kiln exit oxygen. The nanograms NO as NO₂ per joule is 768 at reference baseline conditions (1.82 percent O₂, 2460°F) and 665 at low excess air conditions (0.71 percent O₂, 2477°F); the resultant reduction is 16 percent.

The kiln exit oxygen, material temperature and clinker rate were used to generate the multiple linear regression equation for the dependent process variable. The percent variation in NO emissions associated with kiln exit O₂, material temperature and clinker rate is approximately 30. Table 28 shows the equation for the NO mass emissions along with the correlation coefficient and standard error. The data used for this Method 2 based equation are shown in Tables 24 and 26, and Appendix G-3. The pounds NO as NO₂ per ton of clinker is 8.07 at baseline conditions and is 7.02 at low excess air conditions based on the average input conditions.

The percent reduction of the NO mass emissions (pounds NO₂ per ton of clinker) is 15.7 using the kiln speed derived clinker rate and is 13.0 using the clinker weigh belt scale derived clinker rate. Although the mass emission factors vary by 10 to 14 percent depending on the clinker rate calculations, the percent reduction with LEA from the baseline agrees with the two variations of Method 2 used.

7.4 RAW MIX AND CLINKER ANALYSES

"Ono" evaluations were conducted on two ground samples during the March 1 to 3 low excess air test series. Appendix G-1 summarizes the clinker sample inventory for the low excess air test series. The two clinker samples C-154 (March 1, 2110 hours) and clinker sample C-165 (March 3, 2006 hours) are

TABLE 28. REGRESSION EQUATIONS FOR THE LEA TEST SERIES TO DETERMINE
NO (AS NO₂) POUNDS PER TON OF CLINKER
FEBRUARY 29 - MARCH 3, 1984

CONDITION	NO. OF DATA POINTS (HRS)	METHOD	REGRESSION EQUATIONS	CORR. COEF.	STAND. ERR.
BASELINE	26 (6.5)	2	$\begin{aligned} \text{LB NO(AS NO}_2\text{)} &= -48.48 - .148 * (\text{KILN EXIT O}_2, \text{X}) - .126 * (\text{CLINKER RATE}) \\ \text{TON CLINKER} &+ .025 * (\text{MAT. TEMP., F}) \end{aligned}$	.87	.47
LOWER EXCESS AIR	13 (3.3)	2	$\begin{aligned} \text{LB NO(AS NO}_2\text{)} &= -27.69 + 1.48 * (\text{KILN EXIT O}_2, \text{X}) - .099 * (\text{CLINKER RATE}) \\ \text{TON CLINKER} &+ .015 * (\text{MAT. TEMP., F}) \end{aligned}$	.79	.70
BASELINE AND LOWER EXCESS AIR	39 (9.6)	2	$\begin{aligned} \text{LB NO(AS NO}_2\text{)} &= -43.37 + 1.25 * (\text{KILN EXIT O}_2, \text{X}) - .152 * (\text{CLINKER RATE}) \\ \text{TON CLINKER} &+ .023 * (\text{MAT. TEMP., F}) \end{aligned}$	.86	.56

reported. An "Ono" rating of "good" was assigned to alite birefringence (0.0064 to 0.0076), indicative of maximum temperature; belite size range (20 to 25 microns), and belite color (clear to faint yellow), indicative of cooling rate. A "poor" rating was assigned to alite size range (40 to 60 micron and 45 to 55 microns, respectively), indicative of the heating rate. The C_3S crystals were too large indicating the feed is exposed to temperatures of 1473 to 1723 K for a long time.

The material temperature was on the order of 1500 K (2250°F) for clinker sample C-154 and approximately 1650 K (2500°F) for clinker sample C-165. The low material temperature (2250°F) was associated with a free lime of 1.4 percent.

SECTION 8.0

AS FOUND ROLLING AVERAGE TEST SERIES

While KVB was monitoring kiln emissions and operations for the specific test requirements of the lowered excess air test series, a decision was made to continuously monitor the kiln for a three-day test period and determine rolling averages under as found operating conditions. The objective of establishing this data base was to provide continuous emissions data for approximately a two-day period. Also, comparisons could be made with the 90 hours of nonconsecutive as-found data reported in Section 5.0.

8.1 LONG-TERM ROLLING AVERAGES

The volumetric emissions data along with the clinker rates and coal rates were used to generate 3-hour and 24-hour rolling averages. The data was collected from 3/1 (1600 hours) to 3/3 (1500 hours). Forty-nine consecutive hours of operations and emissions data were collected from the control room strip charts (Appendix G-1) and the clinker weigh belt and coal weigh belt integrators. Table 29 shows the 3-hour rolling average data and Table 30 shows the 24-hour rolling average data, respectively.

The volumetric emissions data were digitized from the control room strip chart with an Apple graphics tablet menu. An hourly emissions average for NO (as measured, ppm) and kiln exit O₂ was then used to generate the three hour rolling averages and 24-hour rolling average for the volumetric emissions.

The clinker weigh belt integrator and coal weigh belt scale integrator were read once an hour and used as the basis for the clinker rate and coal rate determination (tons/hour). It has been noted previously the clinker production rate signal lags the kiln clinker discharge to the clinker cooler grates by approximately 20 to 25 minutes on the average. Since the clinker production rate signal can only be approximately time sequenced with the emissions data, it was decided not to correct the clinker rate to coincide with the long term emissions data. Thus, the clinker rate would be 20 to 25 minutes out of phase for the 3-hour and 24-hour rolling averages. A clinker rate time corrected to the emissions data becomes less significant with longer term averaging.

Mass emissions (nanograms NO as NO₂ per joule and pounds NO as NO₂ per ton of clinker) were calculated using Method 2 (see Appendix C-2). The 24-hour rolling averages for this sampling period smoothed the data scatter and fluctuations in the emissions and process rate data evidenced in the 3-hour rolling averages. The 3-hour rolling average ranged from 4.62 to 10.04 pounds NO as NO₂ per ton of clinker; 89 percent of the 3-hour rolling averages were

TABLE 30. 24-HOUR ROLLING AVERAGE DATA SUMMARY
(AS-FOUND DATA)

SITE 4 ROTARY KILN DATA REDUCTION										24 HOUR ROLLING AVE									
DATE	TIME	O2 MEAS			CLIMBER RT			FUEL RT			MBTU			NO2 LB /SCF E-4	NO2 LB /TON	NO2 LB /TON	NO	MO	
		STD	DEV	CI	95	PPH	STD	DEV	CI	95	TON/HR	STD	DEV						CI
3/2/84	1500	2	.48	.2	861	129.54	56.71	45.2	2.82	1.19	9.18	.21	.09	4.98	1.03	1.24	6.69	820	578
3/2/84	1600	1.9	.5	.21	872	136.35	58.43	44.8	2.71	1.14	9.17	.21	.09	5.02	1.05	1.25	6.79	826	581
3/2/84	1700	1.9	.52	.22	879	134.88	56.96	44.6	2.47	1.04	9.17	.21	.09	5.04	1.05	1.26	6.66	833	584
3/2/84	1800	1.9	.53	.22	903	136.5	57.65	44.4	2.67	1.13	9.17	.21	.09	5.06	1.08	1.36	7.08	853	591
3/2/84	1900	1.9	.56	.24	915	119.53	50.48	44.1	2.23	1.02	9.17	.2	.09	5.1	1.09	1.41	7.21	864	600
3/2/84	2000	1.9	.57	.24	933	126.05	53.23	43.8	2.22	.94	9.17	.2	.09	5.13	1.11	1.44	7.4	884	620
3/2/84	2100	1.9	.58	.24	952	123.48	52.15	43.8	2.11	.89	9.18	.26	.09	5.14	1.14	1.47	7.55	902	632
3/2/84	2200	1.8	.54	.24	965	130.83	55.25	43.8	2.13	.89	9.18	.26	.11	5.13	1.15	1.46	7.9	919	638
3/2/84	2300	1.8	.57	.24	983	144.06	60.84	43.5	1.73	.73	9.16	.26	.11	5.16	1.17	1.51	7.99	926	644
3/2/84	2400	1.8	.54	.23	992	140.52	59.34	43.9	2.74	1.16	9.15	.26	.11	5.16	1.18	1.53	7.99	935	656
3/3/84	100	1.7	.52	.22	1007	150.34	63.5	43.8	2.4	1.14	9.15	.26	.11	5.12	1.2	1.54	7.89	944	662
3/3/84	200	1.7	.48	.2	1015	147.08	62.12	44.4	2.87	1.21	9.15	.26	.11	5.12	1.21	1.55	7.92	952	665
3/3/84	300	1.7	.46	.2	1030	135.61	57.27	43.9	2.86	1.21	9.16	.26	.11	5.12	1.23	1.57	8.06	966	671
3/3/84	400	1.6	.44	.19	1042	135.07	56.2	44.4	3.92	1.66	9.15	.26	.11	5.05	1.24	1.59	8.03	972	682
3/3/84	500	1.6	.4	.17	1051	132.44	56.02	44.6	4.03	1.7	9.15	.26	.11	5.03	1.25	1.6	8.07	980	689
3/3/84	600	1.6	.39	.16	1063	122.81	51.87	44.6	4.03	1.7	9.15	.26	.11	5.03	1.27	1.62	8.16	991	697
3/3/84	700	1.6	.38	.16	1072	119.06	50.28	44.6	4.03	1.7	9.15	.26	.11	5.03	1.28	1.64	8.23	1000	703
3/3/84	800	1.5	.32	.13	1075	119.76	50.58	44.7	4.01	1.69	9.15	.27	.11	5.02	1.28	1.63	8.19	997	702
3/3/84	900	1.5	.29	.12	1082	115.98	48.28	45	4.11	1.74	9.15	.27	.11	4.99	1.29	1.64	8.2	1004	707
3/3/84	1000	1.5	.27	.11	1081	114.32	48.12	45.3	4.11	1.73	9.15	.27	.11	4.95	1.29	1.65	8.15	1003	707
3/3/84	1100	1.5	.28	.12	1095	125.46	52.99	45.4	4.07	1.72	9.15	.27	.11	4.94	1.31	1.67	8.24	1016	717
3/3/84	1200	1.5	.28	.12	1100	122.22	53.73	45.5	4.02	1.7	9.15	.27	.11	4.93	1.31	1.68	8.26	1021	726
3/3/84	1300	1.5	.28	.12	1113	132.01	58.18	45.5	3.98	1.68	9.11	.21	.09	4.91	1.34	1.71	8.4	1042	736
3/3/84	1400	1.5	.29	.12	1135	122.18	57.45	44.4	4.41	1.86	9.11	.2	.09	4.86	1.36	1.73	8.42	1053	745
3/3/84	1500	1.5	.3	.13	1141	121.41	57.27	46.3	4.46	1.89	9.11	.2	.08	4.82	1.36	1.74	8.42	1059	750
																		* FUEL RATE CORRECTED FOR BURNER/SILO 1 W20	
																		NO ON A MASS BASIS IN TERMS OF NO2	

* FUEL RATES CORRECTED FOR BURNER/SILO X H2O

NO ON A MASS BASIS IN TERMS OF NO2

above 6 pounds NO (as NO₂) per ton of clinker. Figure 23 shows the distribution of the 3-hour rolling average emission factor on a pound NO (as NO₂) per ton of clinker basis and the kiln exit O₂, respectively. The 24-hour rolling average ranged from 6.67 to 8.47; 100 percent of the 24-hour rolling averages were above 6 pounds NO (as NO₂) per ton of clinker. Figure 24 shows the distribution of the 24-hour rolling average emission factor on a pound NO (as NO₂) per ton of clinker basis and the kiln exit O₂, respectively. The 24-hour rolling average data helped to minimize the amplitude of variations (pounds NO as NO₂ per ton of clinker) observed on a short term basis.

8.2 CLINKER CHEMISTRY

Figure 25 shows a time trace of the free lime content with NO (ppm, 3 percent O₂) and material temperature (°F) for some of the hourly average data of the 3-day test period. The material temperature of approximately 2375°F and above seemed to be suitable for maintaining satisfactory free lime below 0.5 percent.

"Ono" evaluations were made on ground clinker samples C-152 (March 1, 1907 hours) and C-158 (March 2, 0105 hours). The sample C-152 was Ono rated "good" for the alite size range (25 to 35 microns) indicating the temperature profile was suitable for the time dependent C₃S crystal size. The sample C-158 was "fair" on alite birefringence and "poor" on alite size range which indicates the feed was subjugated to temperatures of 1473 to 1723 K (2192 to 2642°F) for a short period of time. The belite size range was rated as "excellent" which is verified by the steadiness of material temperature of approximately 2400°F. Belite color was yellow indicating a slow cooling rate.

An analysis of two unground clinker samples (sample C-152 and sample C-158) polished section was also performed. The alite crystals were small to medium sized (20 to 40 microns) and well formed (C-152) while the alite crystals were large in size and fairly well formed (45 to 65 microns) for sample C-158.

The belite crystals occurred mainly in clusters and were high in abundance (size range 15 to 25 microns) for sample C-152 while the belite crystals occurred in some clusters and were large to medium sized (25 to 30 microns). The C₄AF was normal in amount with good reflectivity (oxidizing conditions) for C-152 with a kiln exit O₂ of approximately 1.5 percent average. The C₄AF was normal in amount for C-158 but a poor reflectivity in the tan areas indicated localized reducing conditions. The kiln exit O₂ was actually higher (approximately 2.5 percent) for during clinker sample collection (C-158) than C-152.

No raw feed samples were collected during the low excess air test series.

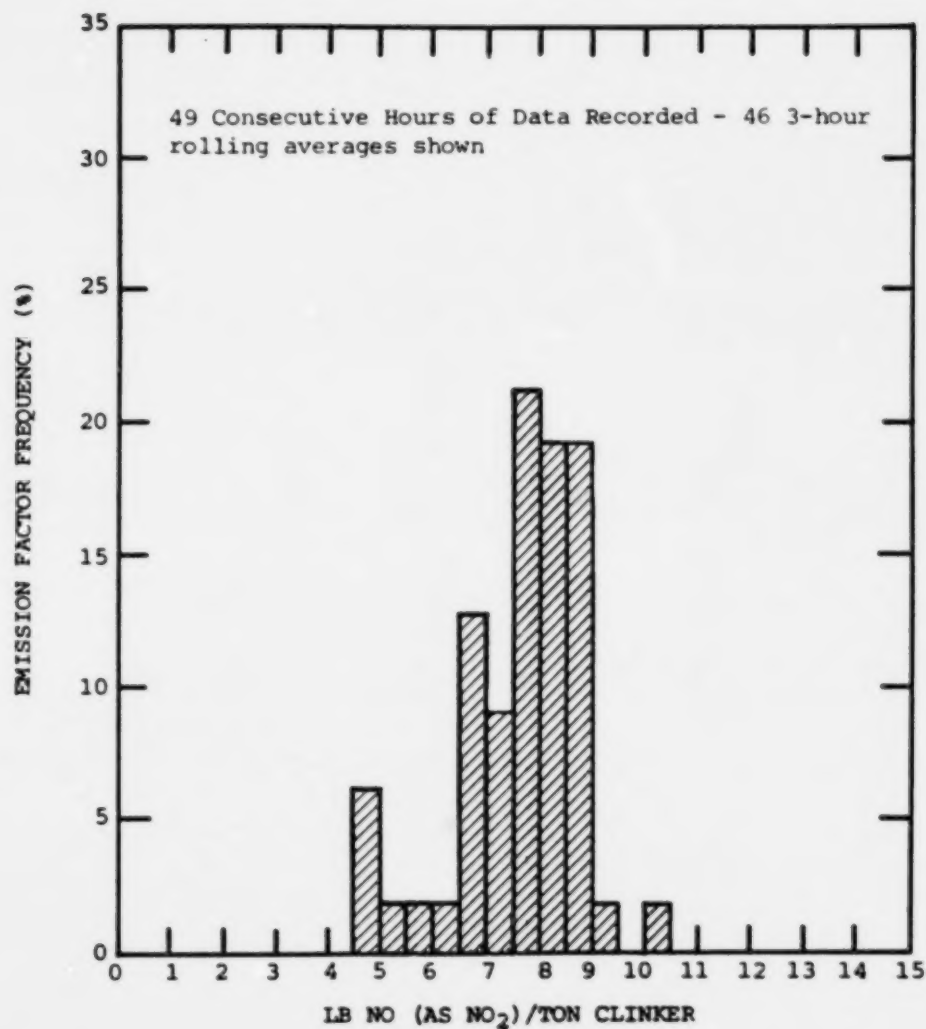


Figure 23. Frequency distribution of 3-hour rolling average emissions factor (lbs NO₂/ton clinker) for March 1-3.

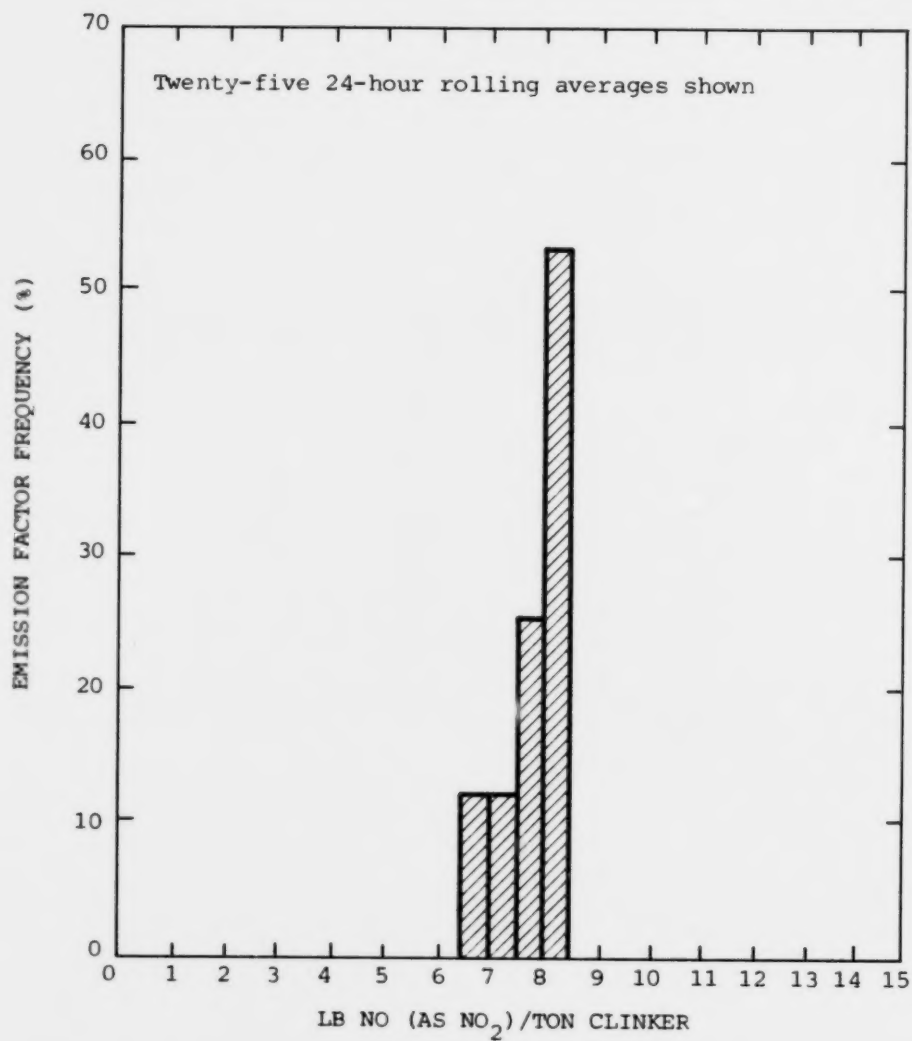


Figure 24. Frequency distribution of 24-hour rolling average emissions factor (lbs NO₂/ton clinker) for March 1-3.

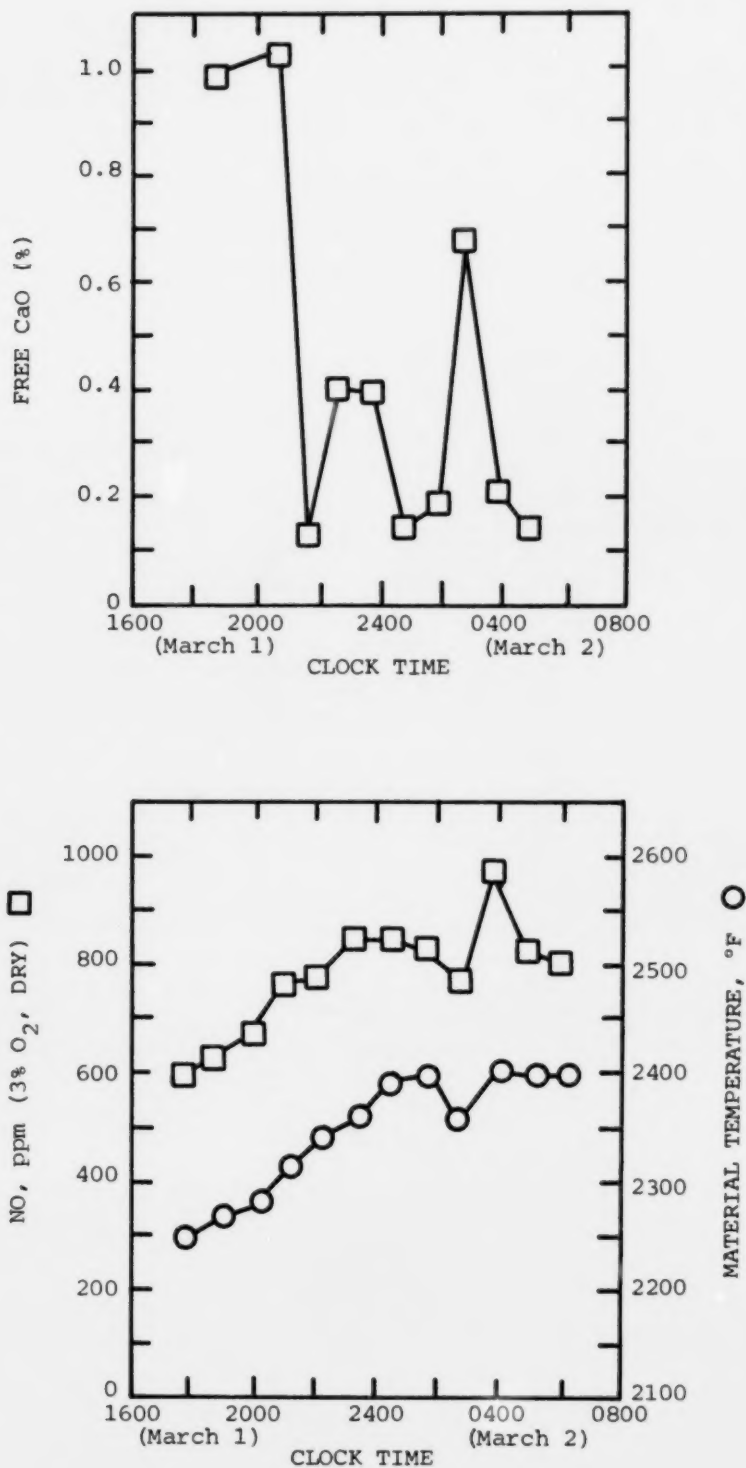


Figure 25. Time Trace of Free Lime, NO, and Material Temperature

SECTION 9.0

DISCUSSION OF RESULTS

The results discussion is aimed at the reasons for process variability and the effects on emissions data for both the as-found data and nitrogen injection data.

9.1 AS-FOUND DATA

The 17 days of collecting operations and emissions data for the "as-found" kiln conditions were valuable for understanding the complexities of long dry kiln operation. The time weighted average coefficient of variation of 31 percent for the NO volumetric emissions data was indicative of the emission variations. The reasons for these variations are numerous. A recurring reason is linked to feed composition changes. The feed composition change will essentially alter the burning zone characteristics as well as the kiln back end operation. An easier burning feed would require less heat input per unit feed while a harder burning feed would require more heat input per unit feed. The fuel heat input rate is normally run at the maximum level by the plant. When feed composition changes do occur, the kiln speed is normally used as the operational control to keep the operations as steady as possible.

Although a Type II feed was burned during 15 of the 17 days of as-found testing, subtle changes in the same feed type can still alter kiln operation. A change from a harder burning feed to an easier burning feed resulted in high kiln shell temperature and loss of coating. Another result of feed composition changes is the formation of rings in the burning zone. The ring acts as a dam and backs up feed in the burning zone. When the ring breaks, the result is a surge or "push" of cool feed which could cause the burning zone to cool down too fast. A review of the emissions data with burning zone temperature has shown that feed composition changes which affect burning zone will also affect NO emissions.

Method 1 NO mass emission factors were too high while Method 2 NO mass emission factors were too low. The CO₂-derived clinker rate (Method 1) did not compare that favorably with the kiln feeder speed/kiln speed and clinker scale derived clinker rate (Method 2). The average entrainment and ignition loss numbers used in the clinker rate calculation were not accurate enough to provide reasonable clinker rate numbers. Conversely, the kiln feeder speed and the factor of 17 feeder revs per ton of clinker provided high clinker rates and lower than expected thermal heat input per ton of clinker. Methods One and Two provide a range of values (e.g. 7.96 to 8.83 lb NO as NO₂ per ton of clinker) but an absolute number for the as-found data is not advisable for reporting or using.

While pushes, coating loss, and dams were part of the day-to-day operational situation, the operation changes to combat these problems are also important for understanding NO emissions data. As mentioned earlier, kiln speed adjustments were typically made to maintain proper burning zone temperature. The key is the frequency of adjustment and magnitude of adjustment based on operator discretion. These adjustments to stabilize kiln operation may or may not be successful.

The as-found NO emissions data reflect the gamut of operating conditions for the test kiln. The Method Two long term rolling averages (3-hour and 24-hour) showed that the NO mass emission cluster between 6.5-9.0 pounds NO (as NO₂) per ton of clinker. Approximately 85 percent of the 3-hour rolling averages fall within the range specified above while 80 percent of the 24-hour rolling averages fall between 7.5 to 8.5 pounds NO (as NO₂) per ton of clinker. The previously established baseline of 5.65 pounds NO (as NO₂) per ton of clinker does fall within the data range of this study, but appears to be anomalous relative to the data cluster.

9.2 NITROGEN INJECTION TEST SERIES

The results from the three days of nitrogen injection testing (November 15, November 17, and April 17) show that the primary air vitiation (lowering mill exit O₂) can have an appreciable impact on NO emissions. The basis for the NO emissions reduction with nitrogen injection was more clearcut on the April 17th test day rather than the November 15th and November 17th test days. November 15th was a shakedown test day for nitrogen injection while the November 17th data are obscured by kiln hood draft change combined with nitrogen injection, lowering kiln exit O₂ to unacceptable combustion conditions. The regression analyses show that NO emissions on a nanogram per joule basis were decreased approximately 27 percent on a pounds NO (as NO₂) per ton of clinker basis (Method 2). The NO emissions reduction were based on a steady kiln exit oxygen level of 1.4 to 1.5 percent for both the reference baseline and nitrogen injection test conditions. The nitrogen injection (lower primary air O₂) lengthens the flame based on the changes observed in the burning zone temperature profile and ignition delay based on movies filmed for baseline and nitrogen injection conditions. The mix chemistry analysis indicates that the burnability factor was fluctuating through the test series (influencing NO emissions). Also, the fuel flow was lowered and later raised to allow for increases and decreases in the nitrogen injection flow rate to the primary air stream. Operations between the selected baseline and nitrogen injection test conditions were not identical for calculating NO emissions reduction. While the fuel flow was less (10.0 ÷ 9.6 tph) and the burnability factor of the mix slightly more (indicating harder burning feed), the kiln speed had been lowered 6 to 8 rph to maintain the burning zone temperature profile which should offset the other two changes and maintain approximately the same burning zone temperature profile. The change in the monitored burning zone temperature between the reference baseline and nitrogen injection tests is more attributed to the nitrogen injection rather than the operational changes which took place.

The short-term NO reduction potential may depend on the operator cushion (material temperature and kiln exit O_2 prior to nitrogen injection. If the burning zone temperature is extremely high where the clinker free lime is between 0.1 to 0.2 percent and constant feed composition and overburning are occurring (large cushion), the mill outlet O_2 could be gradually lowered to 12-13 percent without losing burning zone temperature for good clinker. The burning zone is pushed further back into the kiln but there is still enough heat in the burning zone to maintain good clinker, as denoted by free lime. In fact, no operational changes may be necessary. The resultant NO reduction potential then appears to be very good if starting point material temperature is high. As the operator's cushion diminishes prior to nitrogen injection (neither overburning or underburning), the number of operational changes needed to make good clinker would increase (e.g. kiln speed changes to maintain the heat in the burning zone) with added nitrogen. The resultant NO reduction potential then appears to be very poor since the burning zone temperature is near optimum for the heat input per ton of clinker.

9.3 LEA TEST SERIES

The low excess air test series consisted of establishing reference baseline kiln exit oxygen concentration from which a percent reduction in NO_2 mass emissions could be established for a satisfactory minimum oxygen operating point. The kiln exit oxygen was lowered from an average kiln exit oxygen of 1.8 percent to a level of 0.7 percent. The lower limit on the kiln exit oxygen was based on maintaining acceptable combustibles for continuous operation.

The percent reduction on a nanograms/joule basis was established as 16 percent. The percent reduction on a pounds NO (as NO_2) per ton of clinker basis was established as 15.7 percent using the kiln speed derived clinker rate and is 13.0 using the clinker weigh belt scale derived clinker rate.

SECTION 10.0

QUALITY ASSURANCE

The objective of this section is to not only document data quality but also discuss some of the limitations of the data and problems associated with attaining quality assurance. Results of an internal audit are also presented in this section as well as Appendix I.

10.1 ASSESSMENT OF DATA QUALITY

Assessment of data quality is reviewed for procedures used in collecting and processing data, quantitative analysis, and limitations of data and their use. The following discussion is geared for evaluating the attainment/nonattainment of quality assurance and quality control objectives for the data base on a qualitative as well as a quantitative basis (i.e., precision, accuracy, representativeness, completeness, comparability).

The data quality objectives and overall quality assurance/control are based on the quality assurance plan written by KVB and approved by EPA (Ref. 7). The expectations of the program were focused on evaluating primary air vitiation by collecting enough gaseous emissions data and process control information to make a proper evaluation. The data collected would characterize the variability of NO emissions based on kiln feed variability and control room operational changes.

Emphasis was placed on gathering those emissions data critical to evaluating NO variation with primary air vitiation. The critical gaseous emissions data were essentially NO, O₂, and CO at the kiln backend for all test series and, in addition, primary air O₂ during the nitrogen injection test series. No completeness objectives were formalized for fuel and kiln feed input, clinker quality and control room operations. The data quality objective for solid samples and control room process control was to collect enough samples and operations data to adequately characterize kiln operation during a specific test and explain the variability of NO emissions.

10.1.1 Procedures for Collecting and Processing Data

Frequent instrument calibrations were conducted to insure that the sample emissions were valid. The trailer gaseous emissions instruments were zeroed and spanned once an hour during each test series. The oxygen analyzer for monitoring mill outlet oxygen during the nitrogen injection test series was calibrated more frequently. The instrument checks were made to correct for any significant drifts during the sample collection.

During the as found test series, the steadiness or unsteadiness of kiln operation was not critical for data collection. Steady operation became more

of a concern for evaluating NO reduction potential with nitrogen injection and lowered excess air. The similarities and differences with data collected for each test series of the program are discussed below.

For all test series, the relevant control room strip charts monitoring gaseous emissions and kiln operations were collected, labelled and presented in the appendices. The purpose of presenting these strip charts is to show how changes in kiln operation impact specifically the NO emissions and material temperature. Also, the charts show the steadiness and/or unsteadiness of kiln operation during the test day. The emissions data were useful to compare with the trailer gaseous emissions data. This crosscheck was utilized to insure that the trailer gaseous emissions were suitable for use in calculating mass emissions data. Kiln operations data were monitored to understand the operational changes necessitated to steady kiln operation.

Data such as clinker weigh belt scale integrator readings, coal weigh belt scale integrator readings and kiln feeder revs counter readings were not recorded on strip chart and thus had to be recorded at specific time intervals. These readings were used to calculate clinker rate, kiln feeder rate and coal feed rate. The integrator readings were recorded on an infrequent basis during the as-found test series but regularly recorded during the nitrogen injection and low excess air tests. Calculated clinker rates with the kiln feeder revs counter were compared to the clinker rates derived from kiln feeder speed strip chart and the clinker weigh belt scale integrator.

Although strip charts were useful for recounting the emissions and operational data for a particular testing day, the reasons for operational changes (e.g. kiln speed change, clinker cooler grate speed, I.D. damper opening) may not be apparent based on the strip chart recordings. The operator may make adjustments or prepare to make adjustments based on the burning zone picture via a television camera. A ring or push may be observed and is not necessarily visible on the strip chart recordings, thus, a daily log of the reasons for major operation changes was kept.

Clinker samples were collected approximately three to five times daily during the as-found testing series. The timeliness of the clinker sample collection was not critical to the overall testing but rather an indication if the clinker was being overburned or underburned. KVB collected these clinker samples from two locations. Some of the samples were collected at the kiln discharge, prior to landing on the clinker cooler grate. Other samples were collected at the clinker weigh belt scale. The latter choice was preferable for all clinker sample collection but not always suitable if either clinker transport belt (test kiln or sister kiln) was out of service. Both KVB and the host site analyzed the samples for free lime based on the analytical procedures spelled out in Appendix B.

During the nitrogen injection tests, the frequency of clinker collection was increased to every 15 minutes for reference baseline and nitrogen injection tests. These samples were collected and analyzed by the host site based on previous agreement between KVB and the host site. It was felt that

a higher frequency and analysis of clinker samples would be beneficial for interpreting short term and long term changes in clinker production quality with and without nitrogen injection.

The kiln emissions data (as found test series and reference baseline/low excess air test series) are reported on a fifteen minute average basis. A data point per minute for fifteen minutes is stored in computer memory, averaged then printed. This time increment was felt to be sufficient for as found data since the duration of testing averaged approximately five hours a day and provide enough data points (20 data points) to perform statistical analyses.

The kiln emissions data for the reference baseline/nitrogen injection test series was recorded on a per minute basis with five minute time interval typically used as an averaging basis. The duration of testing under each set of conditions was not long; thus data had to be recorded on a more frequent basis for statistical analysis and eventual use for linear regression analysis.

Several methodologies were used in this study to compare the NO mass emissions data, clinker rates and the thermal input per ton of clinker produced. The objective of calculating the mass emissions data using the various methodologies was to generate a range of values by which confidence could be established in the emission values. While each methodology does have its shortcomings and the accuracy of the measurements involved for each method render one method less attractive than the others. The uncertainty of each method was discussed in Section 4 of the report. Methods 1 and 2 were used throughout the report.

Statistically, cement kiln emissions data were presented in this report in terms of the arithmetic mean, sample standard deviation and the 95 percent confidence interval. During the ongoing data validation in the field, data outliers due to the automatic drain system on the condenser or calibration data accidentally recorded as sample data were eliminated from consideration for further statistical treatment.

Linear regression analyses were performed on the reference baseline and nitrogen injection test series to quantify any reduction potential. The dependent process variables chosen were NO (as NO₂) nanograms per joule and NO (as NO₂) pounds per ton of clinker. The NO (as NO₂) nanograms per joule was correlated with material temperature and kiln exit O₂. The other analysis included a correlation of the dependent process variable, pounds NO (as NO₂) per ton of clinker, with the independent process variables, material temperature, clinker rate and kiln exit O₂. The objective of the regression analysis is directed towards establishing normalized operating conditions (e.g. same kiln exit O₂ and material temperature) by which NO emissions can be reviewed for baseline and nitrogen injection tests.

10.2 INTERNAL AUDIT

Two internal audits were conducted on the jobsite by the KVB Quality Assurance Officer. The audits included the following items:

- . Field accuracy check on NO emissions data
- . Field check on accuracy of NO calibration gas cylinders
- . Measurement of percent O₂ in the coal mill outlet.

The first audit was run on October 12, 1983, and consisted of a field accuracy check on the NO_x emissions data from the test van and a field check on the accuracy of the NO_x calibration gas cylinders. Appendix H summarizes the results of this first audit. Triplicate EPA Method 7 samples were used as the reference to which the other data were compared. Copies of the lab analyses and field reports are also attached.

For the lower cal gas a difference of +58 ppm was found which corresponds to a +10.6 percent deviation from reference. The higher cal gas showed a +86 ppm difference, or a deviation of +7.7 percent. Both of these values are within the designated QA objective of 20 percent accuracy.

Simultaneous sampling of the flue gas in parallel with the van data was performed with the reference method. The NO_x data were both corrected to 3 percent O₂ to account for differences in observed O₂ levels in the Method 7 sample. Using the corrected NO_x values, the test data by the instrumented van was low by 89 ppm or a -11 percent deviation. This, however, was well within the QA objective of 20 percent.

The second audit was performed on November 17, 1983, and consisted of a field audit of the N₂ injection test; specifically, the percent O₂ in the diluent N₂ gas stream. A copy of the Engineering Division Field Report is attached. This report indicates that there was an on-site change in the frequency of data logging the O₂ readings (from one to two minutes/data point), but that this was considered acceptable due to the long test period (3 hrs) and the stability of the O₂ levels. The site-specific QA completeness objective of 85 percent for this data was met on both test occasions when 100 percent of the test data points were logged.

10.2.1 Data Quality Documentation

The data quality is documented for precision, accuracy, completeness, representativeness and reproductibility. A definition for each of the five parameters is included prior to discussion of the data collected during this program. Accuracy is a measure of the bias in a system determined by comparison of the measured value and reference value. Precision is best expressed in terms of the standard deviation for a measure of mutual agreement among individual measurements. Completeness is a measure of the amount of valid

data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal conditions. Representativeness expresses the degree to which data accurately and precisely represents a sampling point or condition. Comparability expresses the confidence with which one data set can be compared with another (either through redundant tests at similar process conditions or through analysis of other reports with rotary kiln data such as Ref. 1).

The precision and accuracy of the TECO 10A analyzer for NO_x measurement was previously assessed by an internal audit. The result of that test were presented in Reference 8. Precision and accuracy of the other instruments have been assessed in previous studies (Ref. 8), but were not repeated for these test series.

Table 31 summarizes the completeness goals for this program and the attainment/nonattainment of these goals. Completeness objectives were satisfied for kiln exit NO , O_2 , CO_2 and CO during the tests under all test conditions. N_2O measurements were made in addition to the gaseous emission data during the as-found test series. The completeness objectives were not satisfied for NO_2 and SO_2 emissions during the as-found test series.

Six coal samples were collected during the as-found testing phase. Although the six samples by no means represent the total number of testing days for as-found conditions, the sample analysis compared well with the weekly host site analyses of the past few months. The coal shipment arrives from one source, the company owned mine in Utah. The two ultimate analyses are felt to adequately represent the daily coal analysis.

10.2.2 Limitations of Data and Their Use

The pollutant emission data cited in this report pertain to one specific classification of cement kilns, i.e. long dry kilns. These data should not be used to estimate mean emissions from other types of kilns or to predict emission reduction potentials of combustion modifications until the modifications have actually been carried out on the different kilns types.

NO_x measurements were made on a dry basis; thus all emissions data and reduction potentials are reported for NO . Conditions in the pilot-scale kiln were not sufficiently steady to allow accurate differential determination of NO_2 .

Although approximately 90 hours of as-found data were recorded and analyzed for mass emissions, this 90 hours of data may or may not be representative of kiln operation, 24 hours a day 7 days a week. The calculated cumulative mass emissions factor (Methods 1 and 2) are representative only of specific times and operating conditions of those seventeen days. These methods are only as good as the input data (measurements) and the accuracy of the instrumentation if regularly calibrated (Section 3.0). When the daily mass emission data or cumulative missions data are cited, the duration of testing (time of day for testing, and the operational conditions should be cited with the emissions data.

TABLE 31. COMPLETENESS OBJECTIVES

Measurement Parameter (Method)	Completeness Goal	As-Found Test Series	Reference Baseline	Nitrogen Injection	LEA
NO (monitor)	90	100	100	100	100
NO ₂ (monitor)	50	0	0	0	0
SO ₂ (monitor)	90	0	0	0	0
O ₂ (monitor)	90	100	100	100	100
O ₂ (portable)	85	NA	NA	100	NA
CO ₂ /CO (monitor)	90	98/67	100/100	100/100	100/100
Opacity	90	NA	NA	NA	NA
Hydrocarbon (GC)	90	0	0	0	0
SO ₃ (ST)	70	NA	NA	NA	NA
N ₂ O (GS)	70	100	0	0	0
Particulate	70	0	0	0	0
Particle Size	70	0	0	0	0

(GC) = gas chromatograph with sample obtained in evacuated flask

(GS) = grab sample of liquid or solid material obtained in appropriate container, delivered to laboratory for analysis

(ST) = sample extraction train

NA = not applicable

LEA = Low Excess air test series

10.3 QA PROBLEMS AND SOLUTIONS

The biggest concern for evaluating NO reduction potential with nitrogen injection or lowered excess air by damper adjustments was maintaining kiln operations as steady as possible from test to test. If changes did occur (as happened on several occasions), a new baseline was established from which NO reduction potential with lowered excess air (either by nitrogen injection or ID damper adjustments) could be evaluated under similar operating conditions to the baseline. This technique helped establish the confidence levels from which lowered excess air could be judged for NO reduction potential.

The evaluation of the NO reduction potential with nitrogen injection or lowered excess air is most difficult to establish because of fluctuating kiln operating conditions. The data with nitrogen injection was normalized to reference baseline conditions for common kiln exit oxygen level and material temperatures. Data analysis has already shown the correlation between NO emissions and material temperature or burning zone temperature. The material temperature from the control room strip charts was used to generate a series of linear regression equations for NO (ng/joule) and NO (pounds per ton of clinker). The problem with this correlation is matching the trailer NO data timewise with the control room material temperature data. If the trailer emissions data and material temperature were recorded simultaneously on the computer, the correlation would be timewise correct. Although the correlation coefficient was not 1.0 for the regression analyses, the linear relation between NO emissions (nanograms per joule) and material temperature and kiln exit oxygen was established.

Another difficulty was the decision to begin nitrogen injection. The criteria for nitrogen injection are a kiln operating in a fairly steady mode (little or no cycling), a sufficiently high material temperature for acceptable clinker (free lime analysis) and an kiln exit oxygen level high enough for sufficiently high nitrogen flow rates. Even if the chart pens were drawing straight lines on NO, O₂, material temperature strip charts, etc., this is not to say the kiln feed composition has changed in the kiln and not been reflected on the control room strip charts. Thus, another criteria for nitrogen injection was that no kiln feed silos changes in the foreseeable future (for the duration of the testing) would be occurring. A kiln feed silo change did occur on November 15th, which drastically affected kiln shell temperature and burning zone temperature.

SECTION 11.0

REFERENCES

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7. KVB, Inc., "Quality Assurance Plan for Emission Control by Advanced Combustion Modification Technology for Industrial Combustion Equipment," EPA Contract No. 68-02-3690, September 1983.
8. Benson, R. C., "Evaluation of Natural Draft and Forced Draft Staging Air Systems for NO Reduction in Refinery Process Heaters," Vol. I, EPA-600/7-84-080a, NTIS PB 84-229640, August 1984.

APPENDIX A-SECTION 1.0

GASEOUS EMISSIONS TEST METHODS AND INSTRUMENTATION

All emission measurement instrumentation were carried in a 9.8 m x 2.4 m (8 x 42 ft) mobile laboratory trailer. A plan view of the trailer is shown in Figure A-1. The gaseous species measurements were made with analyzers located in the trailer.

The emission measurement instrumentation included the following:

TABLE A-1. EMISSION MEASUREMENT INSTRUMENTATION

Species	Manufacturer	Measurement Method	Model No.
Carbon Monoxide	Beckman Instruments	IR Spectrometer	865
Oxygen	Teledyne	Polarographic	326A
Carbon Dioxide	Beckman Instruments	IR Spectrometer	864
Nitrogen Oxides	Thermo Electron Co.	Chemiluminescent	10A

A-1.1 GAS SAMPLING AND CONDITIONING SYSTEM

A flow schematic of the flue gas sampling and analyzing system is shown in Figure A-2. The sampling system uses a positive-displacement diaphragm pumps to continuously draw flue gas from the stack into the laboratory. The sample pump pulls from one unheated sample lines. The probe is connected to the sample pump with 0.95 cm (3/8") or 0.64 cm (1/4") nylon line. The positive displacement diaphragm sample pump provide unheated sample gas to the refrigerated condenser (to reduce the dew point to 35°F), a rotameter with flow control valve, and to the O₂, NO, CO, and CO₂ instrumentation. Flow to the individual analyzers is measured and controlled with rotameters and flow control valves. Excess sample is vented to the atmosphere.

A-1.2 INSTRUMENTAL CONTINUOUS MEASUREMENTS

The laboratory trailer is equipped with analytical instruments to continuously measure concentrations of NO, NO₂, CO, CO₂, and O₂. However, NO₂ was not measured during this program. All of the continuous monitoring instruments and sample handling system are mounted in the self-contained mobile laboratory. The entire system requires only connection to on-site

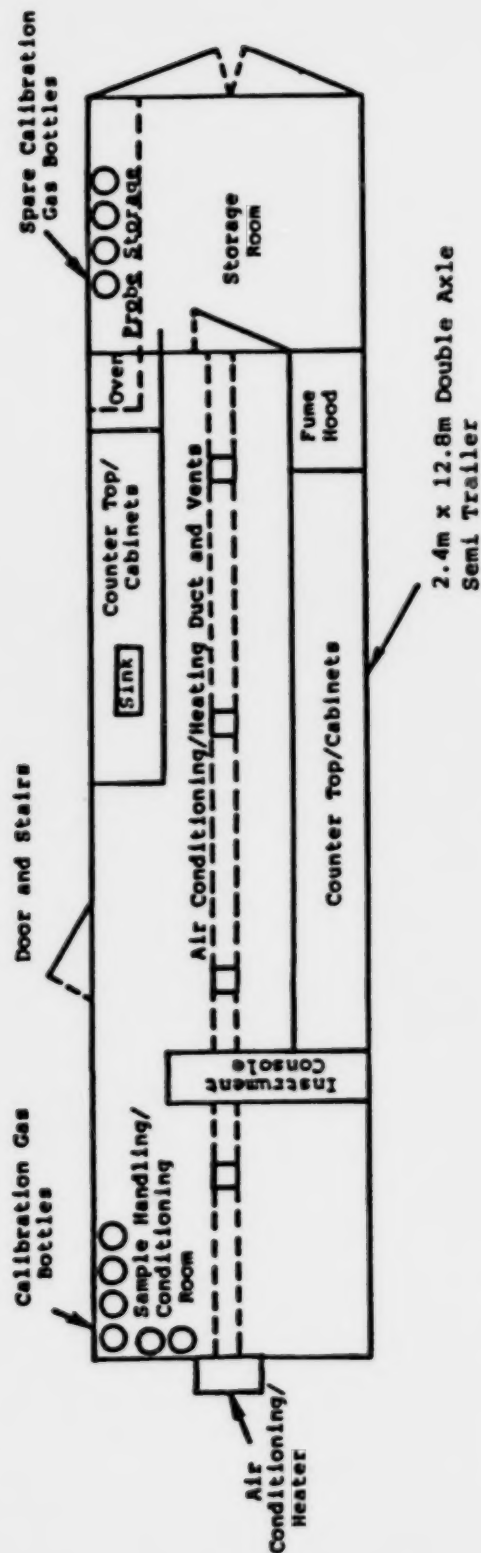


Figure A-1. Instrumentation trailer floor plan.

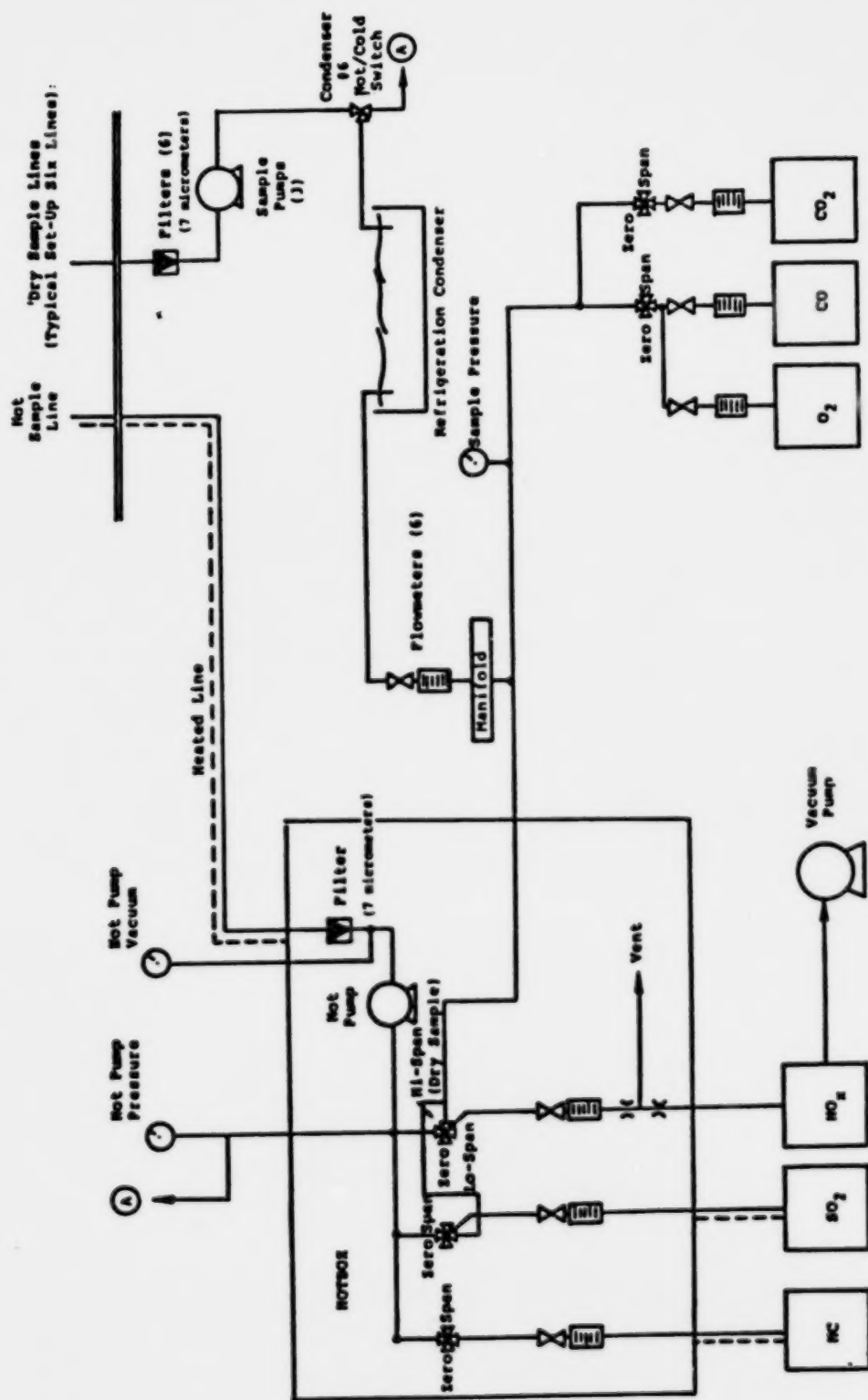


Figure A-2. Flue gas sampling and analyzing system.

water, power, and sampling lines to become fully operational. The instruments themselves are shock mounted on a metal console panel. The sample flow control measurement, and selection, together with instrument calibration are all performed from the console face. Three-pen recorders provide a continuous permanent record of the data taken. The sample gas is delivered to the analyzers at the proper condition and flow rate through the sampling and conditioning system described in the previous section. The sections below describe the analytical instrumentation.

A-1.2.1 Nitric Oxide (NO) and Total Nitrogen Oxides (NO_x)

Both the total nitrogen oxides (NO_x) and nitric oxide (NO) concentrations are measured from a sample gas obtained using a heated sample line at 394 K (250°F). In addition, the nitric oxide concentrations are measured sequentially from samples obtained using the unheated sample line that is connected to the same analyzer in the laboratory trailer. In the latter case, water is first removed from the sample gas by a refrigeration unit. The analytical instrument that is used for all of these measurements is the Thermo Electron Model 10A chemiluminescent gas analyzer.

For NO analyses, the sample gas is passed directly into the reaction chamber where a surplus of ozone is maintained. The reaction between the NO and the ozone produces light energy proportional to the NO concentration which is detected with a photomultiplier and converted to an electrical signal. Air for the ozonator is drawn from ambient through an air dryer and a 10-micrometer filter element.

The chemiluminescent reaction with ozone is specific to NO. To detect NO₂, a thermal converter has been designed to dissociate the NO₂ to NO by the bi-molecular reaction: $2 \text{NO}_2 + 2 \text{NO} + \text{O}_2$. A model 700 thermal converter is used in conjunction with the chemiluminescent gas analyzer as shown in Figure A-3. The converter is a coil of resistance-heated stainless steel tubing whose purpose is to drive the NO₂/NO ratio to its chemical equilibrium value at the converter temperature and pressure. The unit is designed to operate at a temperature of 923 K (1200 °F) and pressure of .3 kPa (10 torr). For these conditions and typical stack gas O₂ concentrations, the equilibrium NO₂ concentration is 0.2 percent of the total NO_x concentration. Therefore, when a gas sample containing any NO₂ is passed through the converter, essentially all the NO₂ would be converted to NO. The resulting total NO is then measured using the chemiluminescent analyzer and the difference between the actual NO and the "total NO" would be the sample NO₂ concentration. The "total NO" is interpreted as NO_x.

NO₂ may react upon contact with H₂O (liquid phase) to form HNO₃ (nitric acid). Under field test conditions, the exhaust gas may contain significant H₂O (depending upon the process and the ambient meteorological conditions), and it is necessary to convert the NO₂ to NO before the H₂O is allowed to condense in the sampling system. By using the heated sample line and the Thermo Electron Model 700 heated NO_x module, NO₂ concentrations will effectively be measured. In reference to Figure A-3, the sample is maintained

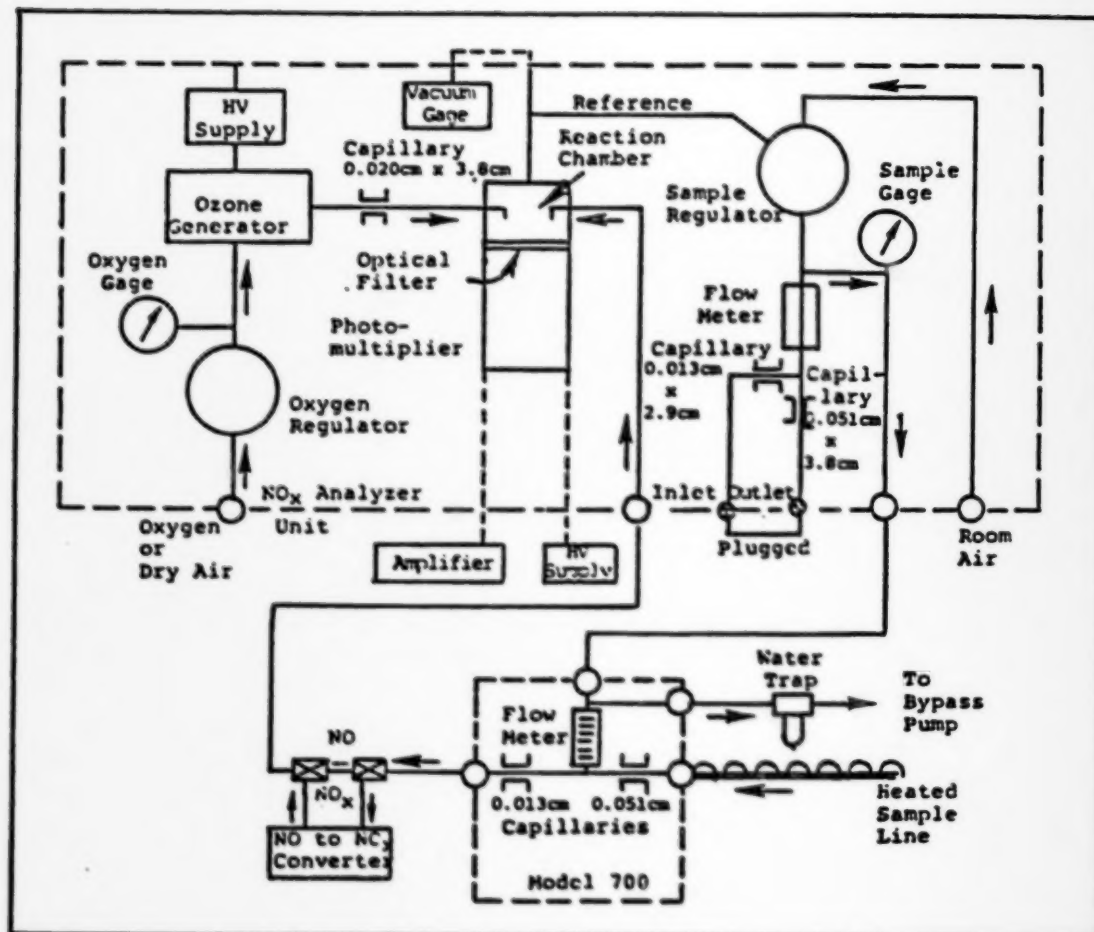


Figure A-3. Schematic of NO_x/NO chemiluminescent analysis system.

above the H₂O dew point up to and through the 127 μ m (0.005 in.) capillary in the heated module. Downstream of this capillary, the flow network is maintained at 1.3 kPa (10 torr), where the partial pressure of the H₂O in the sample is sufficiently low to prevent any condensation at ambient temperature.

When using the heated system, NO, NO₂, and NO_x are measured on a wet basis. When not using the heated system, a condenser is placed upstream of the analyzer and NO is measured on a dry basis.

Specifications

Accuracy:	1% of full scale
Span stability:	$\pm$ 1% of full scale in 24 hours
Zero stability:	$\pm$ 1 ppm in 24 hours
Power requirements:	115 $\pm$ 10V, 60 Hz, 1000 watts
Response:	90% of full scale in 1 sec (NO _x mode); 0.7 sec (NO mode)
Output:	4 to 20 ma
Sensitivity:	0.5 ppm
Linearity:	$\pm$ 1% of full scale
Vacuum detector operation Range:	2.5, 10, 25, 100, 250, 1000, 2500, 10,000 ppm full scale

A-1.2.2 Carbon Monoxide and Carbon Dioxide (CO and CO₂)

Carbon monoxide and carbon dioxide concentrations are measured using Beckman Model 864 and 865 short-path-length nondispersive infrared analyzers (see Figure A-4). These instruments measure the differential in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wavelength absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale of 0 to 100 percent and is then related to the concentration of the species of interest by calibration curves supplied with the instrument. A linearizer is supplied with each analyzer to provide a linear output over the range of interest. The operating ranges for the CO analyzer are 0 to 100 and 0 to 2000 ppm, while the ranges for the CO₂ analyzer are 0 to 5 percent and 0 to 20 percent.

Specifications

Span stability:	± 1% of full scale in 24 hours
Zero stability:	± 1 ppm in 24 hours
Ambient temperature range:	273 to 322 K (32°F to 120°F)
Line voltage:	115 ± 15V rms
Response:	90% of full scale in 0.5 or 2.5 sec
Linearity:	Linearizer board installed for one range
Precision:	± 1% of full scale
Output:	4 to 20 ma

A-1.2.3 Oxygen (O₂)

A Teledyne Model 326A oxygen analyzer is used to automatically and continuously measure the oxygen content of the flue gas sample. The analyzer utilizes a micro-fuel cell which is specific for oxygen, has an absolute zero, and produces a linear output from zero through 25 percent oxygen. The micro-fuel cell is a sealed electrochemical transducer with no electrolyte to change or electrodes to clean. Oxygen in the flue gas diffuses through a Teflon membrane and is reduced on the surface of the cathode. A corresponding oxidation occurs at the anode internally and an electric current is produced that is proportional to the concentration of oxygen. This current is measured and conditioned by the instrument's electronic circuitry to give an output in percent O₂ by volume for operating ranges of 0 to 5 percent, 0 to 10 percent, and 0 to 25 percent.

Specifications

Precision:	± 1% of full scale
Response:	90% in less than 40 sec
Sensitivity:	1% of low range
Linearity:	± 1% of full scale
Ambient temperature range:	273 K to 325 K (32°F to 125°F)
Fuel cell life expectancy:	40,000% +-hrs
Power requirement:	115 VAC, 50 to 60 Hz, 100 watts
Output:	4 to 20 ma

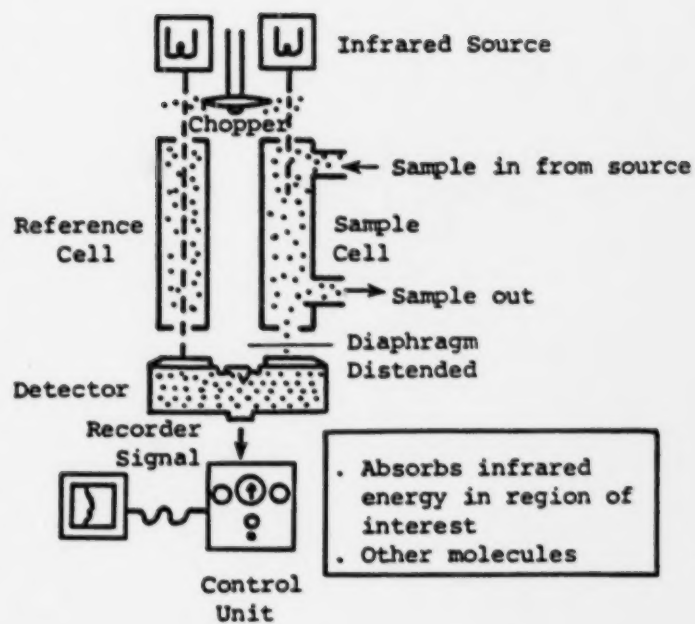


Figure A-4. Schematic of NDIR analyzer.

APPENDIX B

FREE LIME ANALYSIS

Equipment

Burette (0.1-ml subdivision)
Erlenmeyer flask with rubber stopper (250 ml)
Hot plate with stirrer
Thermometer
Teflon-coated magnetic stirring bar
Vacuum filtering flask (250 ml)
Gooch crucible with holder
Glass fiber filter

Reagents

Anhydrous ethylene glycol
0.02N hydrochloric acid (standardized against 0.02N sodium hydroxide which is standardized with potassium acid phthalate)
Phenolphthalein indicator (1% solution in ethanol)

Procedure

A sample (usually 1 g) of ground cement or clinker was accurately weighed into a clean, dry, 250-ml Erlenmeyer flask. It is important that the sample does not come in contact with moisture before extraction. About 50 ml of ethylene glycol, heated to the desired temperature (75 - 85°C) were added to the flask and stirred for the desired amount of time (10 min) using a magnetic stirrer on a hot plate. The temperature was maintained at the desired value and checked frequently. The hot suspension was filtered under suction through a glass fiber filter fitted onto a Gooch crucible and the clean wetted with ethylene glycol before filtering. The Erlenmeyer flask was rinsed at least twice with about 10-15 ml hot ethylene glycol which, after filtering, was added to the original filtrate.

About 25 ml of deionized water and 1 ml of phenolphthalein indicator solution were added to the filtrate and then titrated to a colorless endpoint with 0.02N HCl. Addition of water to the ethylene glycol filtrate facilitates the endpoint determination. Free lime is calculated as follows:

$$\% \text{ Free CaO} = \frac{\text{ml HCl} \times \text{normality of HCl}}{10 \times \text{sample weight}} \times 28$$

APPENDIX C

CONVERSION OF CEMENT KILN EMISSIONS DATA
FROM VOLUME BASIS TO MASS BASIS

APPENDIX C1

METHOD 1

INPUT:

Emissions concentration: NO ppm (dry, measured, at 3% O₂)

O₂, % (dry, measured) (O_{2d})

CO₂, % (dry, measured) (CO_{2d})

Fuel Flowrate measured: (T) $\frac{\text{tons coal}}{\text{hr}}$

Fuel high heating value (analysis): 12260 Btu/lb

Fuel composition (ultimate analysis):	%C	69.32
	%H	4.645
	%S	.545
	%N	1.405
	%O	9.915

Ignition loss: 0.352 $\frac{\text{lbs CO}_2}{\text{lbs feed}}$

Entrainment loss: 0.10

OUTPUT

Fuel firing rate (B) $\frac{10^6 \text{ Btu}}{\text{ton clinker}}$

Evolved flue gas from coal combustion ($F_{d_{\text{fuel}}}$) $\frac{\text{DSCF}}{10^6 \text{ Btu}}$

Evolved gas as CO₂ from cement feed ($G_{d_{\text{CO}_2}}$) $\frac{\text{DSCF}}{\text{ton clinker}}$

Pollutant emission rate (E) $\frac{\text{lbs NO}_x}{10^6 \text{ Btu}}$

Total Pollutant Rate (E_T) $\frac{\text{lbs NO}_x}{\text{ton clinker}} = (B) \times (E)$

$$E_T \frac{\text{lbs NO}}{\text{ton clinker}} = B \frac{10^6 \text{ Btu}}{\text{ton clinker}} \times E \frac{\text{lbs NO}}{10^6 \text{ Btu}}$$

$$B \frac{10^6 \text{ Btu}}{\text{ton clinker}} = \frac{G_{d\text{CO}_2} \frac{\text{DSCF}}{\text{ton clinker}} \times 100 - \frac{20.9}{20.9 - \% \text{O}_{2d}} \% \text{CO}_{2d}}{F_{d\text{fuel}} \frac{\text{DSCF}}{10^6 \text{ Btu}} \times \frac{20.9}{20.9 - \% \text{O}_{2d}} \times \% \text{CO}_{2d} - C(\% \text{C}) \frac{\text{DSCF}}{10^6 \text{ Btu}}}$$

$$F_{d\text{fuel}} = \frac{[1.53 (\% \text{C}) + 3.64 (\% \text{H}) + 0.57 (\% \text{S}) + 0.14 (\% \text{N}) - 0.46 (\% \text{O}_2)] 10^6}{12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV})} = \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$= 9699 \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$G_{d\text{CO}_2} = \frac{385 \frac{\text{DSCF}}{\text{mole}}}{44 \frac{\text{lbs CO}_2}{\text{mole}}} \times \frac{0.352 \text{ lb CO}_2}{\text{lb feed}} \times \frac{2000 \text{ lb/ton}}{[1 - .352(\text{I.L.})] \times [1 - .10(\text{E.L.})]} = \frac{\text{DSCF CO}_2}{\text{ton clinker}}$$

$$= 10562 \frac{\text{DSCF CO}_2}{\text{ton clinker}}$$

$$C(\% \text{C}) = \frac{385 \frac{\text{DSCF}}{\text{mole}} \times 10^6 \times (69.32 \% \text{C})}{12.01 \frac{\text{lb C}}{\text{mole C}} \times 12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV})} = 181253 \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$E \frac{\text{lbs NO}}{10^6 \text{ Btu}} = \frac{\text{NO}_x \text{ ppm (dry, at } 3\% \text{ O}_2) \times 46 \frac{\text{lbs NO}}{\text{lb mole}} \times (N_{\text{DS fuel}} + N_{\text{CO}_2})}{12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV}) \times \frac{20.9 - 3\% \text{ O}_2}{20.9}}$$

$$N_{\text{DS fuel}} = \frac{(\% \text{C})}{251.6} + \frac{(\% \text{H})}{106.9} + \frac{(\% \text{S})}{671.7} + \frac{(\% \text{N})}{2801.6} - \frac{(\% \text{O})}{848.1} = 0.3086 \frac{\text{dry stoich. moles}}{\text{lb fuel}}$$

$$N_{\text{CO}_2} \frac{\text{moles}}{\text{lb fuel}} = \frac{385 \frac{\text{DSCF}}{\text{mole}}}{44 \frac{\text{lb CO}_2}{\text{mole}}} \times \frac{0.352 \text{ lbs CO}_2}{\text{lb feed}} \times \frac{2000 \text{ lb/ton}}{B \frac{10^6 \text{ Btu}}{\text{ton clinker}} \times \frac{1 - .352}{(\text{I.L.})} \times \frac{1 - .10}{(\text{E.L.})}} \times 12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV})$$

$$= \frac{385 \frac{\text{DSCF}}{\text{mole}} \times 10^6}{44 \frac{\text{lb CO}_2}{\text{mole}} \times \frac{0.352 \text{ lbs CO}_2}{\text{lb feed}} \times \frac{2000 \text{ lb/ton}}{B \frac{10^6 \text{ Btu}}{\text{ton clinker}} \times \frac{1 - .352}{(\text{I.L.})} \times \frac{1 - .10}{(\text{E.L.})}} \times 12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV})$$

*Values determined from fuel analysis

APPENDIX C2

METHOD 2

INPUT:

Emissions concentration: NO ppm (dry, measured, at 3% O₂)
 O₂, % (dry, measured), (O_{2d})

Clinker rate (from kiln feeder speed, strip chart data): (C) $\frac{\text{tons clinker}}{\text{hr}}$
 and 17 feeder revolutions/ton clinker

Fuel flowrate measured: (T) $\frac{\text{tons coal}}{\text{hr}}$

Fuel high heating value (analysis): 12260 Btu/lb

Fuel composition (ultimate analysis): %C 69.32
 %H 4.645
 %S 0.545
 %N 1.405
 %O 9.915

Ignition loss: 0.352 $\frac{\text{lbs CO}_2}{\text{lb feed}}$

Entrainment loss: 0.10

OUTPUT:

Fuel firing rate (B) $\frac{10^6 \text{ Btu}}{\text{ton clinker}}$

Evolved flue gas from coal combustion ($F_{d_{\text{fuel}}}$) $\frac{\text{DSCF}}{10^6 \text{ Btu}}$

Evolved gas as CO₂ from cement feed ($F_{d_{\text{process}}}$) $\frac{\text{DSCF}}{10^6 \text{ Btu}}$

Pollutant emission rate (E): $\frac{\text{lbs NO}_x}{10^6 \text{ Btu}}$;

Pollutant concentration ($C_{d_{\text{NO}_x}}$): $\frac{\text{lbs NO}_x}{\text{DSCF}}$

Total pollutant rate (E_T) $\frac{\text{lbs NO}_x}{\text{ton clinker}} = (B) \times (E)$

Where given:

- Emissions concentration - NO ppm (dry, measured)
- Emissions concentration - O₂% (dry, measured) = O_{2d}
- Clinker rate (measured) = $C \frac{\text{tons clinker}}{\text{hr}}$
- Fuel flowrate (measured) = $T \frac{\text{tons coal}}{\text{hr}}$
- Fuel high heating values = $D \frac{\text{Btu}}{\text{lb coal}}$
(from analysis)
- Fuel composition (from analysis)

Also:

$$\text{NO}_x \text{ ppm (dry, at 3\% O}_2) = \text{NO}_x \text{ ppm (dry, measured)} \times \left(\frac{17.9}{20.9 - \text{O}_{2d}} \right)$$

$$B = \text{fuel firing rate} = \frac{10^6 \text{ Btu}}{\text{ton clinker}}$$

$$F_{d_{\text{tot}}} = \text{total evolved gas (from feed and fuel)} \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$F_{d_{\text{fuel}}} = \text{evolved gas from fuel} \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$F_{d_{\text{process}}} = \text{evolved gas as CO}_2 \text{ from cement feed} \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$\text{I.L.} = \text{net ignition loss} \frac{\text{lbs CO}_2}{\text{lb dry feed}}$$

$$E = \text{pollutant emission rate} \frac{\text{lbs NO}_x}{10^6 \text{ Btu}}$$

$$C_{d_{\text{NO}_x}} = \text{pollutant concentration} \frac{\text{lbs NO}_x}{\text{DSCF}} \text{ (at 3\% O}_2)$$

$$E_T = \text{total pollutant emission rate} \frac{\text{lbs NO}_x}{\text{ton clinker}}$$

$$E_T \frac{\text{lbs NO}_x}{\text{ton clinker}} = B \frac{10^6 \text{ Btu}}{\text{ton clinker}} \times E \frac{\text{lbs NO}_x}{10^6 \text{ Btu}}$$

$$B \frac{10^6 \text{ Btu}}{\text{ton clinker}} = T \frac{\text{ton coal}}{\text{hr}} \times \frac{2000 \text{ lb}}{\text{ton coal}} \times \frac{12260 \text{ Btu}}{\text{lb coal}} \times \frac{10^6 \text{ Btu}}{1,000,000 \text{ Btu}} \times C \frac{\text{ton clinker}}{\text{hr}}^{-1}$$

The standard dry basis NSPS procedure for determination of emission rate E is:

$$E \frac{\text{lbs NO}_x}{10^6 \text{ Btu}} = C_{d_{\text{NO}_x}} \frac{\text{lbs NO}_x}{\text{SCF}} \times F_{d_{\text{tot}}} \frac{\text{DSCF}}{10^6 \text{ Btu}} \times \frac{20.9}{20.9 - \% \text{O}_2_d}$$

$$= C_{d_{\text{NO}_x} \text{ at } (3\% \text{O}_2)} \times F_{d_{\text{tot}}} \times \left(\frac{20.9}{20.9 - 3\% \text{O}_2} \right)$$

$$C_{d_{\text{NO}_x}} (\text{at } 3\% \text{O}_2) \frac{\text{lbs NO}_x}{\text{DSCF}} = \text{NO}_x \text{ ppm (dry at } 3\% \text{O}_2) \times 1.194 \times 10^{-7}$$

$$F_{d_{\text{tot}}} = F_{d_{\text{fuel}}} + F_{d_{\text{process}}}$$

$$F_{d_{\text{fuel}}} = \frac{[1.53(\%C) + 3.64(\%H) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{12260 \frac{\text{Btu}}{\text{lb}} (\text{HHV})} \times 10^6 = \frac{\text{DSCF}}{10^6 \text{ Btu}}$$

$$= 9699 \frac{\text{DSCF CO}_2}{10^6 \text{ Btu}}$$

$$F_{d_{\text{process}}} = \frac{385 \frac{\text{DSCF}}{\text{mole}}}{44 \frac{\text{mole}}{\text{mole}}} \times \frac{0.352 \text{ lbs CO}_2}{\text{lbs dry feed}} \times \frac{\text{lb dry feed}}{10^6 \text{ Btu}} = \frac{\text{DSCF CO}_2}{10^6 \text{ Btu}}$$

*Values determined from fuel analysis

$$\frac{\text{lb dry feed}}{10^6 \text{ Btu}} = \frac{2000 \frac{\text{lbs}}{\text{ton}}}{B \frac{10^6 \text{ Btu}}{\text{ton clinker}} \times [1 - .352(\text{I.L.})] \times [1 - 0.10 (\text{E.L.})]}$$

$$\text{I.L.} = (\text{ignition loss}_{\text{feed}} - \text{ignition loss}_{\text{clinker}}) \frac{\text{lbs CO}_2}{\text{lb dry feed}}$$

$$\text{I.L.} = (0.355 - 0.0026)*$$

$$\text{I.L.} = 0.352 \frac{\text{lbs CO}_2}{\text{lb dry feed}}$$

E.L. = entrainment loss (loss of feed due to entrainment)

$$\text{E.L.} = 0.10 \frac{\text{lbs CO}_2}{\text{lb dry feed}} **$$

*Values for ignition losses (feed and clinker) are based on mean values from plant analysis for month of 10/83

**Value for entrainment loss based on plant information

APPENDIX C3

METHOD 3

INPUT:

Emissions concentration: NO ppmv (dry, as measured)

Percent moisture in flue gas: %

Molecular weight of flue gas (M): $\frac{\text{lb}}{\text{lb mole}}$

Flue gas temperature (T_g): °R

Dynamic pressure (ΔP): "H₂O

Static pressure (P_g): "H_g

Clinker rate (C): tons/hr

OUTPUT:

Flue gas flow rate (Q): sdcfm

Total pollutant rate (E_t): $\frac{\text{lbs NO}_x}{\text{ton clinker}}$

$$E_t \frac{\text{lbs NO}_x}{\text{ton clinker}} = \frac{\text{NO} \left(\frac{\text{ft}^3}{10^6 \text{ ft}^3} \right) \times \frac{46 \frac{\text{lb}}{\text{lb mole}}}{385 \frac{\text{ft}^3}{\text{lb mole}}} \times Q (\text{sdcfm}) \times \frac{60 \text{ min}}{1 \text{ hr}}}{C}$$

where Q = flue gas flow rate [sdcfm]

C = clinker production rate $\left[\frac{\text{ton clinker}}{\text{hour}} \right]$

APPENDIX C4

FLUE GAS FLOW RATE, EMISSIONS AND EMISSIONS FACTORS*

1. Kiln No. _____,

1.1 Flue gas flow rate, calculated

1.1.1 Fuel CO₂

$$\left(\frac{\text{tons coal}}{\text{hr}} \right) \left(\frac{\% \text{C}}{100\% \text{ coal}} \right) \left(\frac{44 \text{ ton CO}_2}{12 \text{ ton C}} \right) = \frac{\text{ton CO}_2}{\text{hr}}$$

1.1.2 Feedrock CO₂

$$\begin{aligned} (\text{CO}_2)_{\text{Ca}} &= \left(\frac{\text{ton feed}}{\text{hr}} \right) \left(\frac{\% \text{CaO}}{100\% \text{ feed}} \right) \left(\frac{44 \text{ ton CO}_2}{56.1 \text{ ton CaO}} \right) \\ &= \frac{\text{ton CO}_2}{\text{hr}} \end{aligned}$$

$$\begin{aligned} (\text{CO}_2)_{\text{Mg}} &= \left(\frac{\text{ton feed}}{\text{hr}} \right) \left(\frac{\% \text{MgO}}{100\% \text{ feed}} \right) \left(\frac{44 \text{ ton CO}_2}{40.3 \text{ ton MgO}} \right) \\ &= \frac{\text{ton CO}_2}{\text{hr}} \end{aligned}$$

1.1.3 Total CO₂

$$(\text{CO}_2)_{\text{Total}} = \frac{\text{ton CO}_2}{\text{hr}} + \frac{\text{ton CO}_2}{\text{hr}} + \frac{\text{ton CO}_2}{\text{hr}} = \frac{\text{ton CO}_2}{\text{hr}}$$

1.1.4 Flue gas flow rate at 68°F and 3% O₂, DSCFM

$$\begin{aligned} &\left(\frac{\text{ton CO}_2}{\text{hr}} \right) \left(\frac{\text{hr}}{60 \text{ min.}} \right) \left(\frac{2000 \text{ lb CO}_2}{\text{ton CO}_2} \right) \left(\frac{385 \text{ DSCF CO}_2}{44 \text{ lb CO}_2} \right) \times \\ &\left(\frac{100\% \text{ flue gas}}{\% \text{ CO}_2} \right) \left(\frac{20.9 - \text{O}_2}{20.9 - 3.0} \right) = \text{DSCFM CO}_2 \text{ @ } 68^\circ\text{F @ } 3\% \text{ O}_2 \end{aligned}$$

1.1.4.1 Flue gas rate "as tested"

$$\left(\text{DSCFM @ } 3\% \text{ O}_2 \right) \left(\frac{20.9 - 3.0}{20.9 - \text{O}_2} \right) = \text{SDCFM @ } \text{_____}$$

*Reference: California Air Resources Board

APPENDIX D

UNCERTAINTY ANALYSIS OF METHODS 1, 2, AND 3

METHOD 1 CASE STUDY

Input: $B = 5.66 \frac{\text{MMBtu}}{\text{ton clinker}}$

Output: $\frac{W_B}{B}$ (uncertainty)

X	$\left(\frac{\Delta B}{\Delta X}\right)$	$\frac{\Delta B}{\left(\frac{\Delta X}{B}\right)}$	$\frac{\Delta B^2}{\left(\frac{\Delta X}{B}\right)^2}$	W_X	$\frac{\Delta B^2}{\left(\frac{\Delta X}{B}\right)^2} \times W_X^2$
O ₂	-1.30×10^{-2}	2.28×10^{-3}	5.22×10^{-6}	1.50×10^{-2}	1.00×10^{-9}
CO ₂	-3.40×10^{-1}	5.98×10^{-2}	3.58×10^{-4}	2.96×10^{-1}	3.14×10^{-5}
HHV	4.62×10^{-4}	8.12×10^{-5}	7.00×10^{-9}	9.80×10^1	6.73×10^{-5}
%C	-6.08×10^{-2}	1.07×10^{-2}	1.15×10^{-4}	2.08×10^{-1}	4.98×10^{-6}
%H	-4.21×10^{-1}	7.41×10^{-2}	5.49×10^{-3}	3.25×10^{-1}	5.80×10^{-4}
%S	-6.60×10^{-3}	1.16×10^{-3}	1.35×10^{-6}	5.40×10^{-4}	3.94×10^{-13}
%N	-1.61×10^{-2}	2.83×10^{-3}	8.00×10^{-6}	7.00×10^{-4}	3.92×10^{-12}
%O	-5.33×10^{-2}	9.37×10^{-3}	8.78×10^{-5}	4.96×10^{-2}	2.16×10^{-7}
I.L.	2.48×10^1	4.35×10^0	1.90×10^1	7.04×10^{-4}	9.42×10^{-6}
E.L.	6.29×10^0	1.10×10^0	1.22×10^0	6.30×10^{-2}	4.80×10^{-3}

$$\frac{W_B}{B} = \sqrt{\sum_{i=1}^{10} \left(\frac{\Delta B}{\Delta X}\right)^2 \times W_{X_i}^2} = 7.44\%$$

$$W_B = 0.421 \frac{\text{MMBtu}}{\text{ton clinker}}$$

METHOD 1 CASE STUDY

$$E = 2.13 \frac{\text{lbs NO}_2}{\text{MMBtu}}$$

x	$\left(\frac{\Delta E}{\Delta x}\right)$	$\frac{\Delta E}{\left(\frac{\Delta x}{E}\right)}$	$\frac{\Delta E^2}{\left(\frac{\Delta x}{E}\right)^2}$	w_x	$\frac{\Delta E^2}{\left(\frac{\Delta x}{E}\right)^2} \times w_x^2$
NO ppm, dry @ 3% O ₂	1.61×10^{-3}	7.58×10^{-4}	6×10^{-7}	1.32×10^1	1.05×10^{-4}
HHV	1.45×10^{-4}	6.84×10^{-4}	5.00×10^{-7}	9.81×10^1	4.81×10^{-3}
%C	2.30×10^{-2}	1.08×10^{-2}	1.17×10^{-4}	2.08×10^{-1}	5.05×10^{-6}
%H	5.41×10^{-2}	2.55×10^{-2}	6.48×10^{-4}	3.25×10^{-3}	7.00×10^{-9}
%S	8.61×10^{-3}	4.05×10^{-3}	1.64×10^{-5}	5.40×10^{-4}	4.78×10^{-12}
%N	2.06×10^{-3}	9.71×10^{-4}	9.00×10^{-7}	7.00×10^{-4}	4.41×10^{-13}
%O	6.82×10^{-3}	3.21×10^{-3}	1.03×10^{-5}	4.96×10^{-2}	2.58×10^{-8}
I.L.	1.51×10^0	7.08×10^{-1}	5.01×10^{-1}	7.04×10^{-4}	3.53×10^{-4}
E.L.	3.82×10^{-1}	1.80×10^{-1}	3.23×10^0	6.30×10^{-2}	1.28×10^{-4}
B	5.60×10^{-2}	2.64×10^{-2}	6.94×10^{-4}	4.20×10^{-1}	1.23×10^{-4}

$$\frac{w_E}{E} = \sqrt{\frac{10}{\sum_{i=1} \left(\frac{\Delta E}{\Delta x}\right)^2 \times w_{x_i}^2}} = 7.43\%$$

$$w_E = 0.1580 \frac{\text{lbs NO}_2}{\text{MMBtu}}$$

$$E_T = B \times E = 12.03 \frac{\text{lbs NO}_2}{\text{ton clinker}}$$

$$w_{E_T} = \sqrt{\frac{2}{\sum_{i=1} \left(\frac{\Delta E_T}{\Delta x_i} \times w_{x_i}\right)^2}} = 0.949 \frac{\text{lbs NO}_2}{\text{ton clinker}}$$

$$\frac{w_{E_T}}{E_T} = 7.89\%$$

METHOD 2 CASE STUDY

$$B = 5.66 \frac{\text{MMBtu}}{\text{ton clinker}}$$

x	$\left(\frac{\Delta B}{\Delta X}\right)$	$\frac{\Delta B}{\left(\frac{\Delta X}{B}\right)}$	$\frac{\Delta B^2}{\left(\frac{\Delta X}{B}\right)^2}$	w_x	$\frac{\Delta B^2}{\left(\frac{\Delta X}{B}\right)^2} \times w_x^2$
C ₁	5.86×10^{-1}	1.04×10^{-1}	1.07×10^{-2}	1.93×10^{-2}	2.07×10^{-4}
C ₂	-1.36×10^{-1}	2.40×10^{-2}	5.78×10^{-4}	2.08×10^0	2.50×10^{-4}
HHV	463.9	8.20×10^{-5}	6.72×10^{-9}	9.80×10^1	6.47×10^{-5}

$$\frac{w_B}{B} = \sqrt{\sum_{i=1}^2 \left(\frac{\Delta B}{\Delta X_i}\right)^2 \times w_i^2} = 5.26\%$$

$$w_B = .298 \frac{\text{MMBtu}}{\text{ton clinker}}$$

METHOD 2 CASE STUDY

Input: $E = 2.13 \frac{\text{lbs NO}_2}{\text{MMBtu}}$

Output: $\frac{W_E}{E}$ (uncertainty)

x	$(\frac{\Delta E}{\Delta X})$	$(\frac{\Delta E}{\Delta X})$ (E)	$(\frac{\Delta E}{\Delta X})^2$ (E)	W_X	$(\frac{\Delta E}{\Delta X})^2 \times W_X^2$
NO ppm, dry @ 3% O ₂	1.61×10^{-3}	7.58×10^{-4}	6.00×10^{-7}	1.32×10^1	1.05×10^{-4}
HHV	1.45×10^{-4}	6.84×10^{-4}	5.00×10^{-7}	9.81×10^1	4.81×10^{-3}
%C	2.30×10^{-2}	1.08×10^{-2}	1.17×10^{-4}	2.08×10^{-1}	5.05×10^{-6}
%H	5.41×10^{-2}	2.55×10^{-2}	6.48×10^{-4}	3.25×10^{-3}	7.00×10^{-9}
%S	8.61×10^{-3}	4.05×10^{-3}	1.64×10^{-5}	5.40×10^{-4}	4.78×10^{-12}
%N	2.06×10^{-3}	9.71×10^{-4}	9.00×10^{-7}	7.00×10^{-4}	4.41×10^{-13}
%O	6.82×10^{-3}	3.21×10^{-3}	1.03×10^{-5}	4.96×10^{-2}	2.58×10^{-8}
I.L.	1.51×10^0	7.08×10^{-1}	5.01×10^{-1}	7.04×10^{-4}	3.53×10^{-4}
E.L.	3.82×10^{-1}	1.80×10^{-1}	3.23×10^{-2}	6.30×10^{-2}	1.28×10^{-4}
C ₁	-3.3×10^{-8}	-1.55×10^{-8}	2.41×10^{-16}	1.93×10^{-1}	8.98×10^{-18}
C ₂	8.00×10^{-9}	3.76×10^{-9}	1.42×10^{-17}	2.08×10^0	6.14×10^{-17}

$$\frac{W_E}{E} = \sqrt{\sum_{i=1}^9 \left(\frac{\Delta E}{\Delta X} \right)^2 \times W_{X_i}^2} = 7.35\%$$

$$W_E = 0.1562 \frac{\text{lbs NO}_2}{\text{MMBtu}}$$

$$E_T = B \times E = 12.03 \frac{\text{lbs NO}_2}{\text{ton clinker}}$$

$$= \sqrt{\sum_{i=1}^2 \left(\frac{\frac{\Delta E_T}{\Delta X_i}}{\frac{E_T}{E_T}} \right)^2} \times W_{X_i}^2 = 9.04\% \text{ uncertainty}$$

METHOD 3 CASE STUDY

$$Q = 158,657 \text{ scfm}$$

X	$\left(\frac{\Delta Q}{\Delta X}\right)$	$\left(\frac{\Delta Q}{\Delta X}\right)$	$\left(\frac{\Delta Q}{\Delta X}\right)^2$	W_X	$\left(\frac{\Delta Q}{\Delta X}\right)^2 \times W_X^2$
%H ₂ O = 2.46%	162631	1.025	1.051	±1%	1.05 x 10 ⁻⁴
A = 84 ft ²	1888	0.0119	1.42 x 10 ⁻⁴	0	0
P _S = 28.57" Hg	2776	0.0175	3.06 x 10 ⁻⁴	±3.3%	3.33 x 10 ⁻⁷
ΔP = 0.6915" H ₂ O	114700	0.7229	5.23 x 10 ⁻¹	±0.1%	5.23 x 10 ⁻⁷
T _S = 1000°R	-79.3	0.0005	2.5 x 10 ⁻⁷	±0.5%	6.25 x 10 ⁻¹²
M _S = 29.6 $\frac{\text{lb}}{\text{lb mole}}$	-2679	0.0169	2.86 x 10 ⁻⁴	±1%	2.86 x 10 ⁻⁸

$$\frac{W_Q}{Q} = \sqrt{\frac{6}{\sum_{i=1}^6 \left(\frac{\Delta Q}{\Delta X_i}\right)^2 \times W_{X_i}^2}} = 1.03\%$$

$$E_T = 12.03 \frac{\text{lbs NO}_2}{\text{ton clinker}}$$

$$W_{E_T} = \sqrt{\frac{3}{\sum_{i=1}^3 \left(\frac{\Delta E_T}{\Delta X_i}\right)^2 \times W_{X_i}^2}} = 5.20\%$$

$$W_{E_T} = 0.63 \frac{\text{lbs NO}_2}{\text{ton clinker}}$$

APPENDIX E

AS-FOUND TEST SERIES

APPENDIX E-1

AS-FOUND KILN EMISSIONS AND OPERATIONS DATA FROM
HOST SITE CONTROL ROOM

(Sept. 26 - Sept. 30
Oct. 3 - Oct. 7
Oct. 10 - Oct. 14)

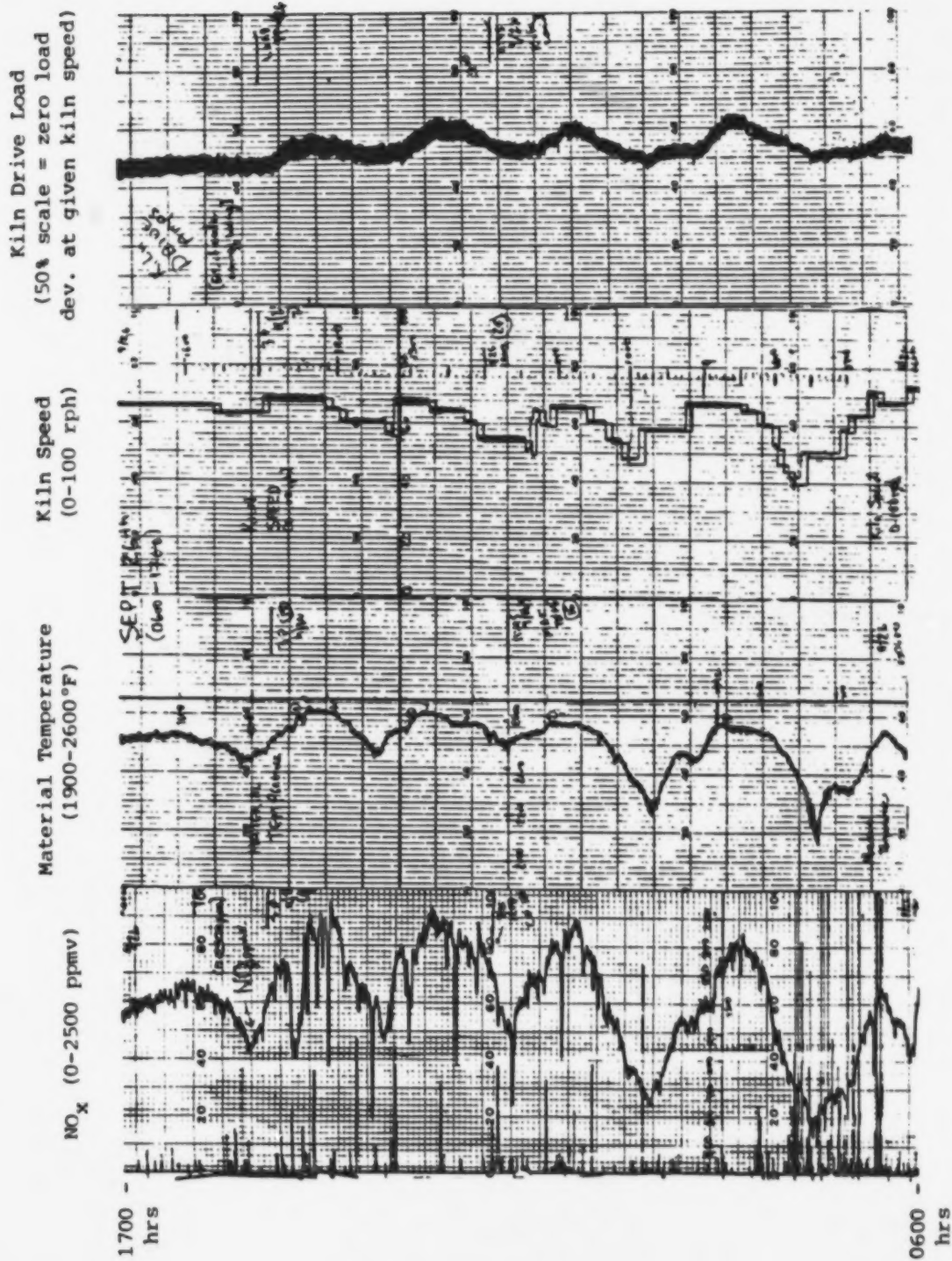


Figure E-1. Sept. 26 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

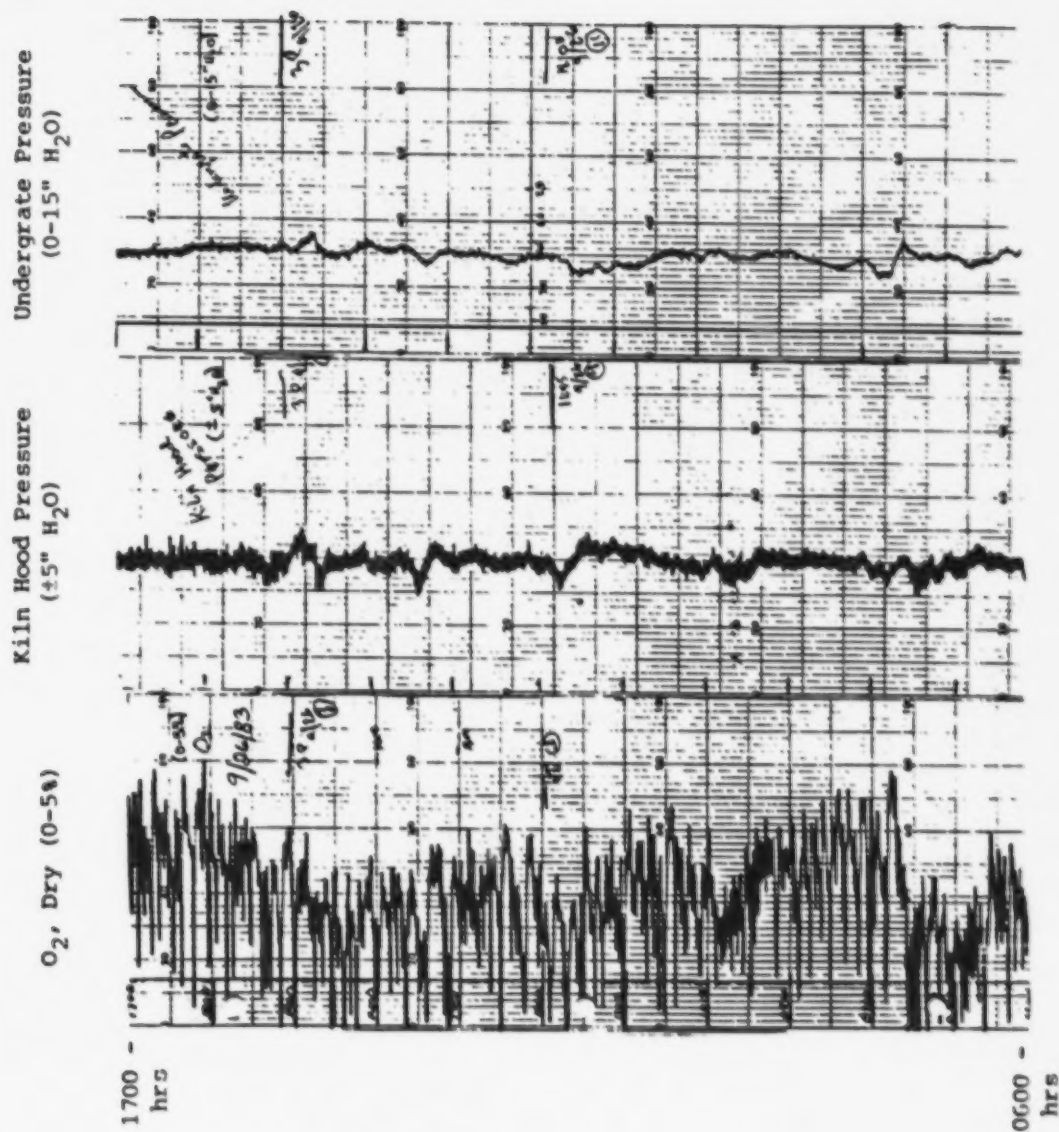


Figure E-2. Sept. 26 (O₂, Kiln Hood Pressure, Undergrate Pressure); 0600-1700 hrs



Figure E-3. Sept. 26 (Clinker Cooler Speed);
0600-1700 hrs

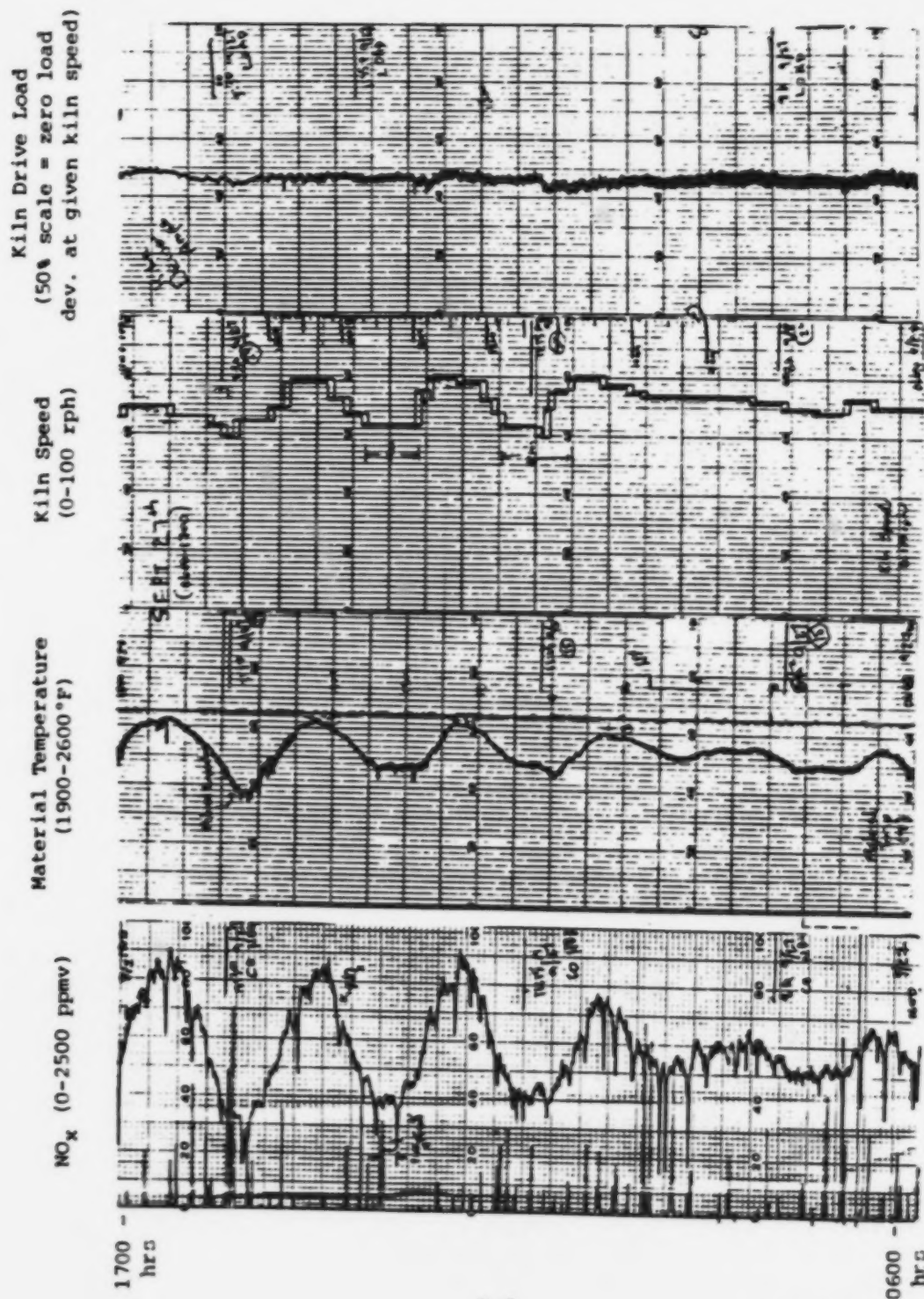


Figure E-4. Sept. 27 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

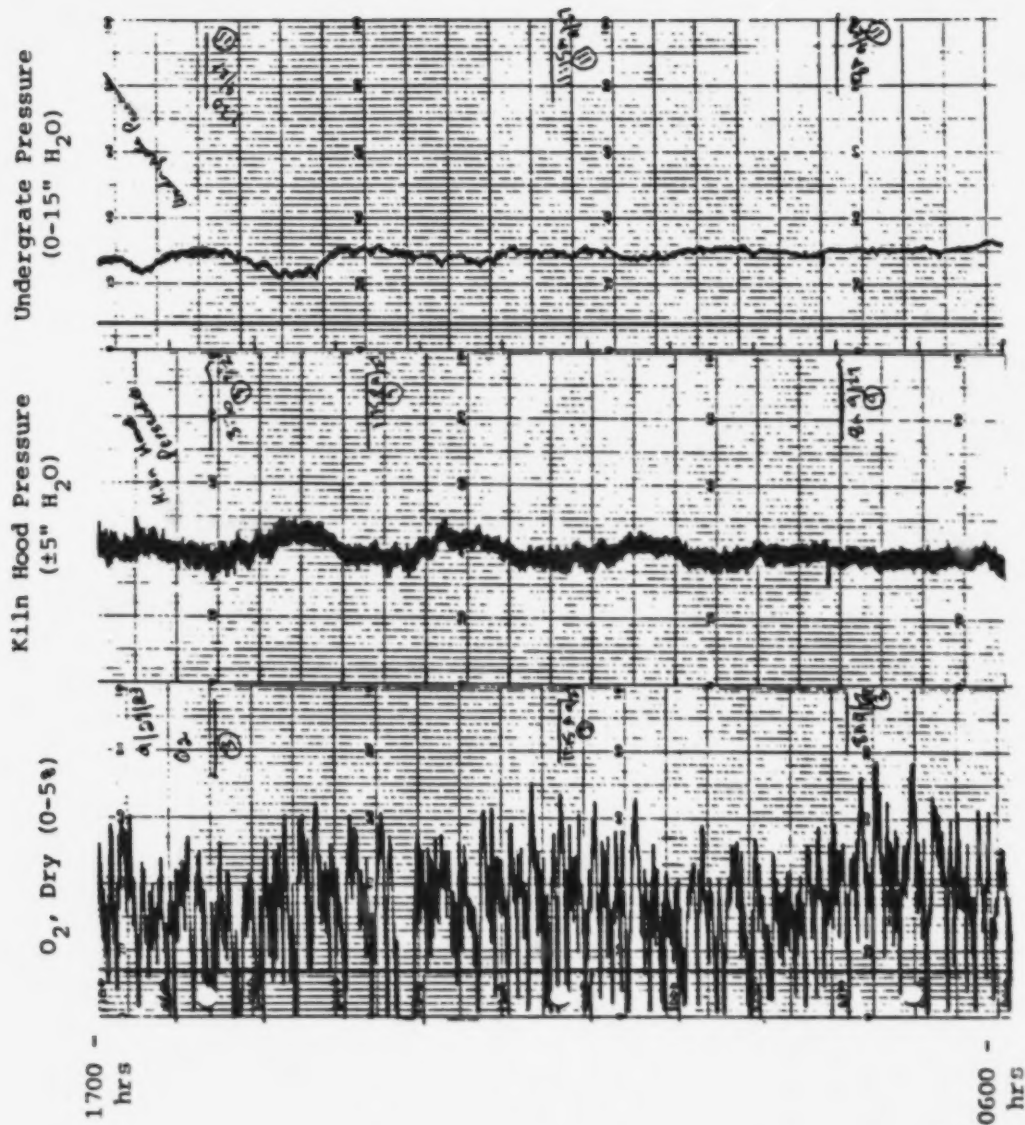


Figure E-5. Sept. 27 (O₂, Kiln Hood Pressure, Undergrate Pressure); 0600-1700 hrs

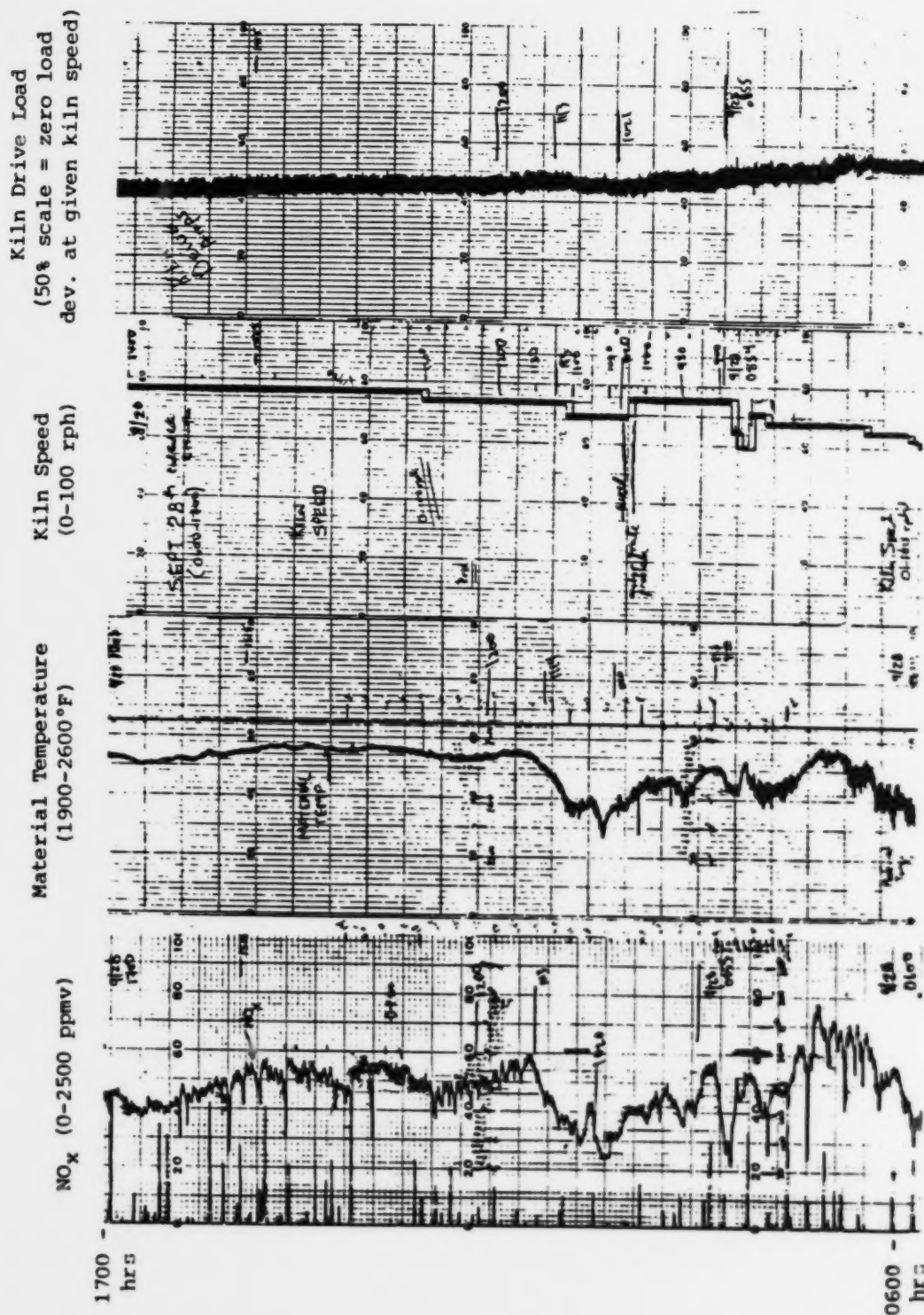


Figure E-7. Sept. 28 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

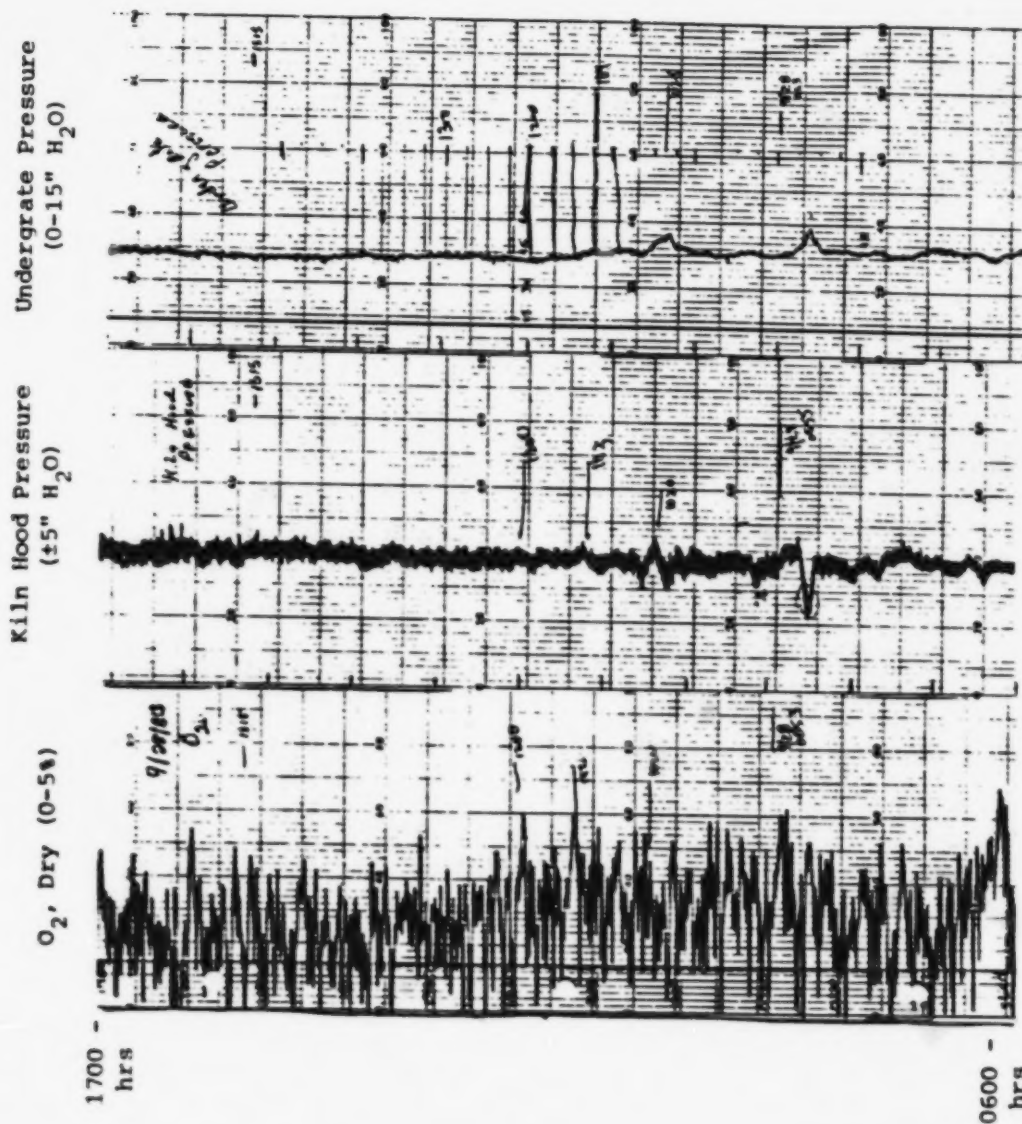


Figure E-8. Sept. 28 (O₂, Kiln Hood Pressure, Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

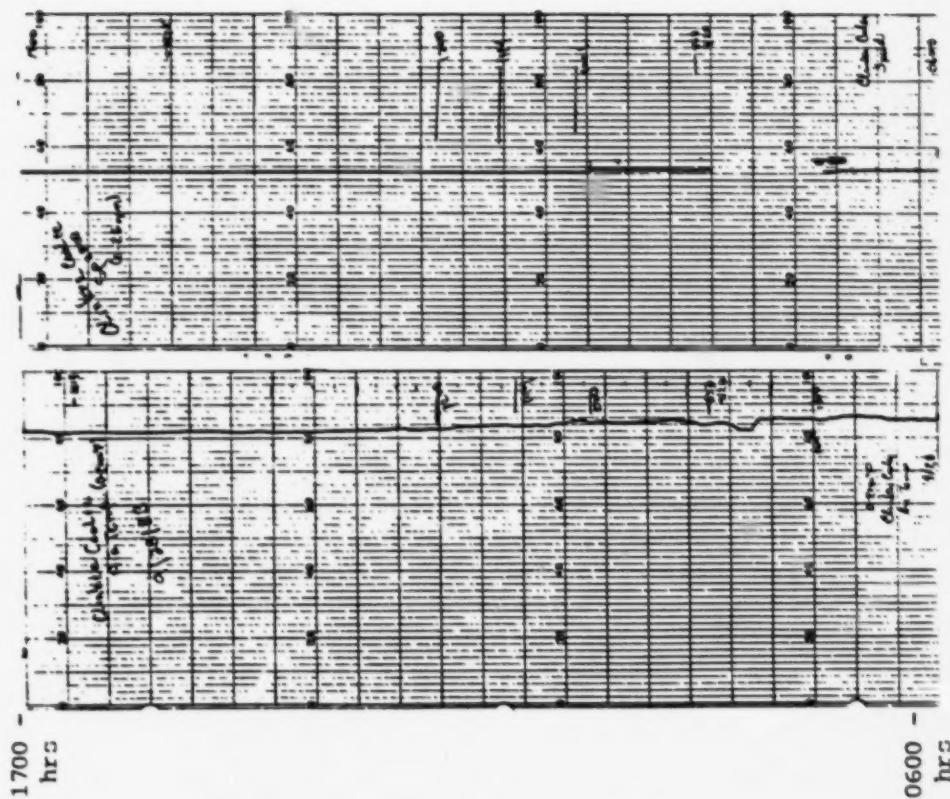


Figure E-9. Sept. 28 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

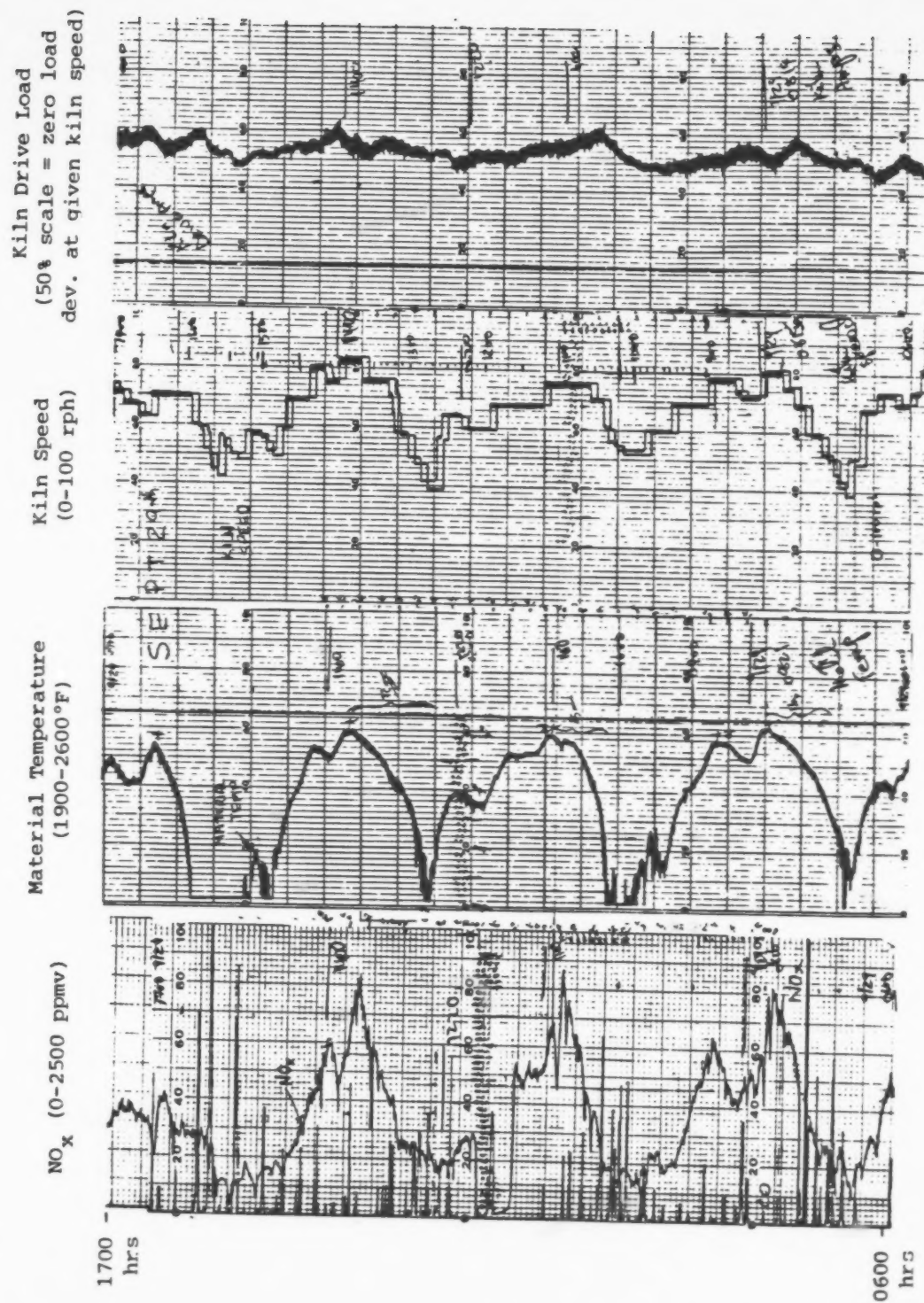


Figure E-10. Sept. 29 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

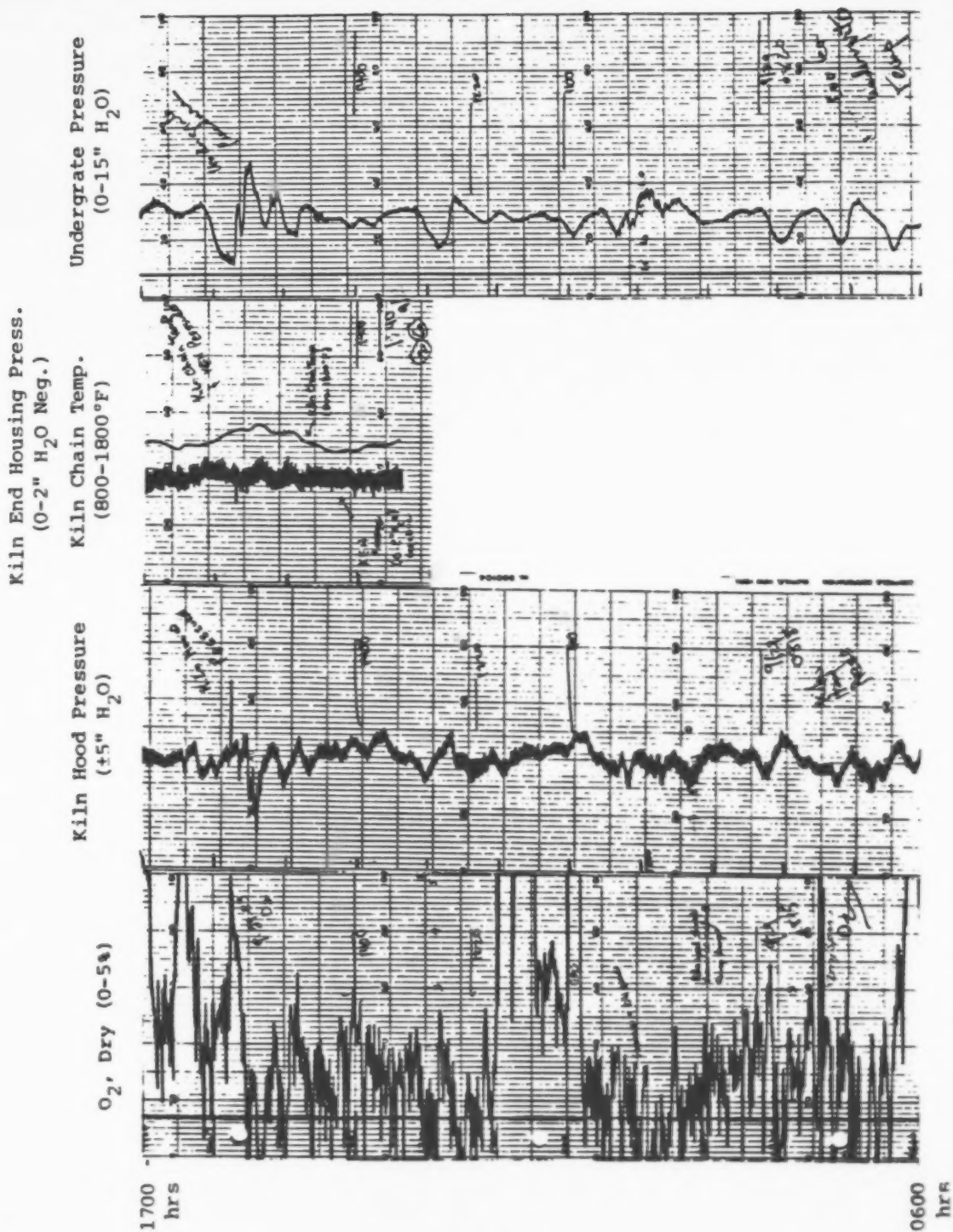


Figure E-11. Sept. 29 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

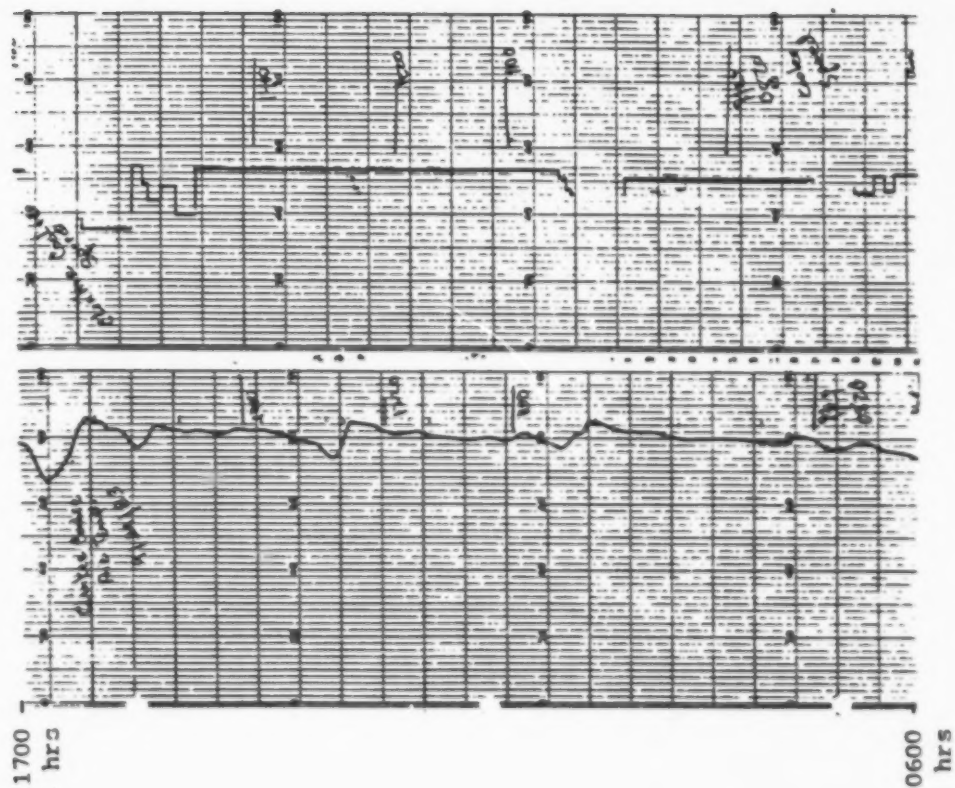


Figure E-12. Sept. 29 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

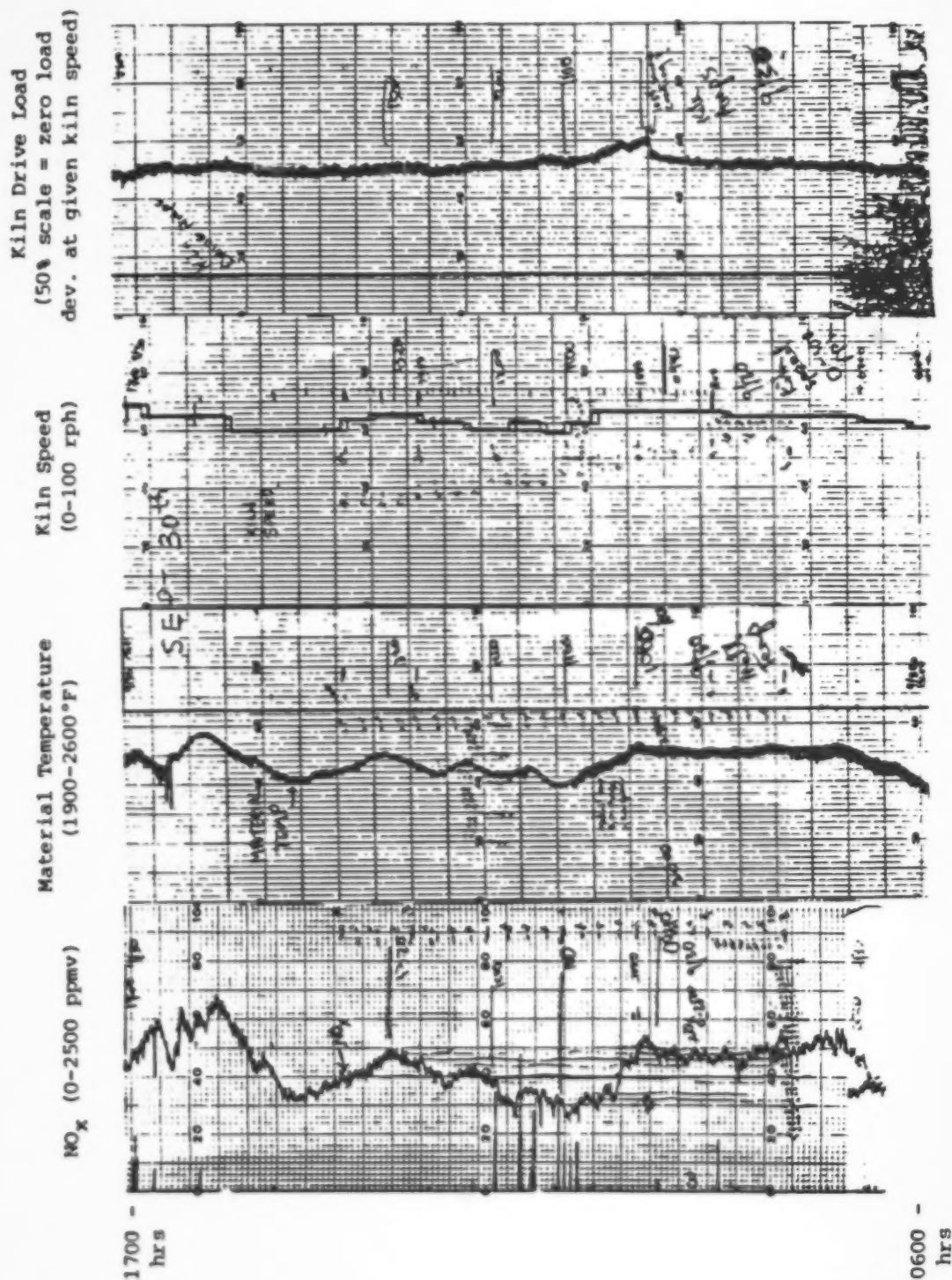


Figure E-13. Sept 30 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

Kiln End Housing Press.
(0-2" H₂O Neg.)

Kiln Chain Temp.
(800-1800°F)

Kiln Hood Pressure
(±5" H₂O)

O₂, Dry (0-5%)

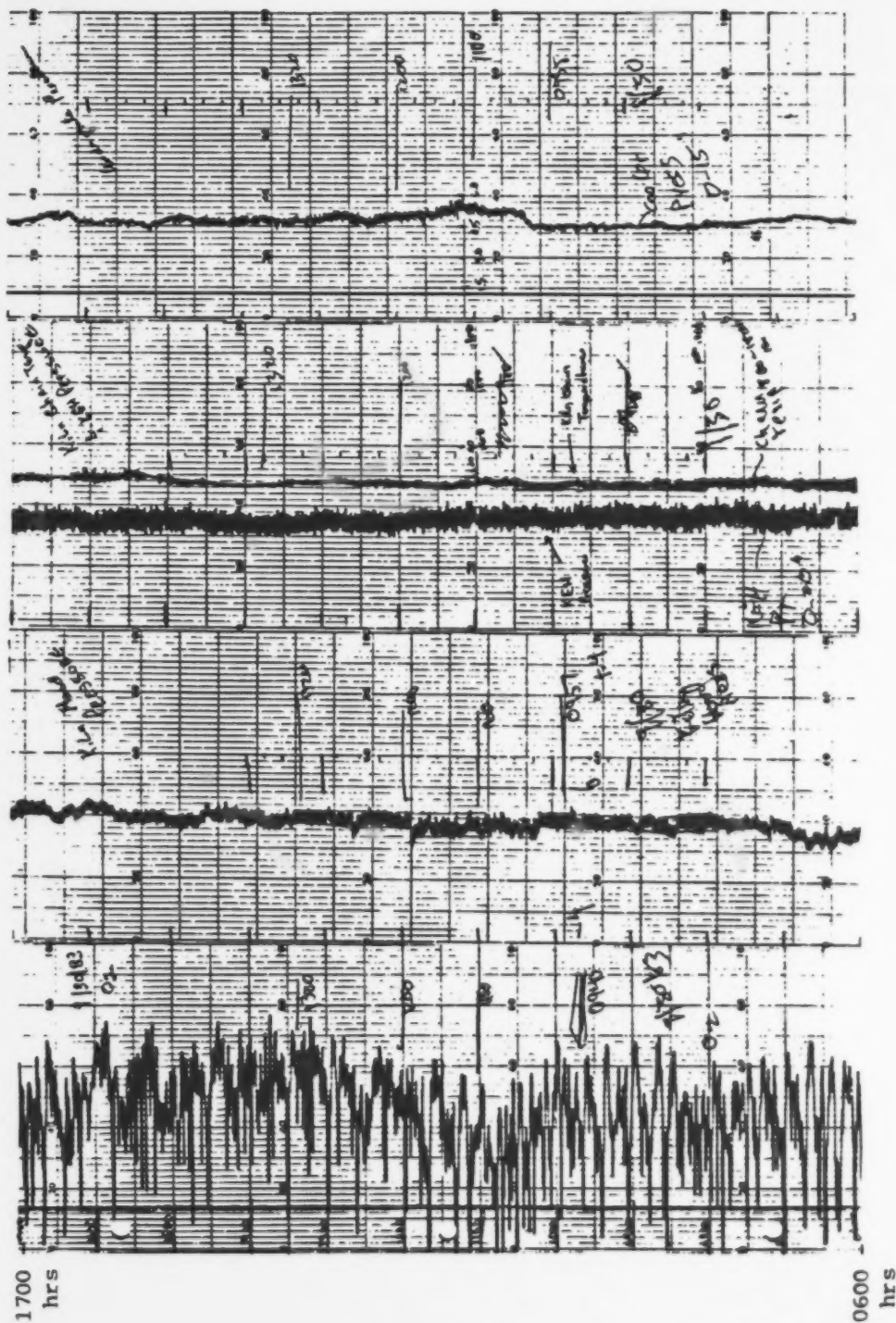


Figure E-14. Sept. 30 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

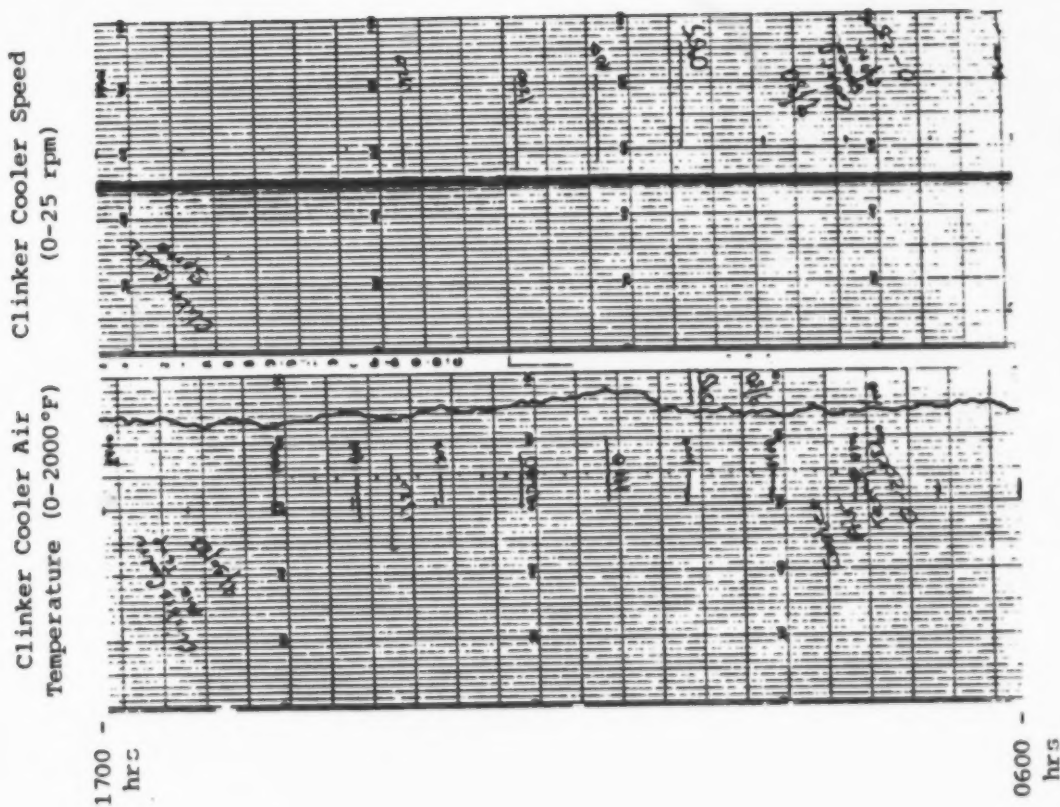


Figure E-15. Sept. 30 (Clinker Cooler Air Temp., Clinker Cooler Speed): 0600-1700 hrs

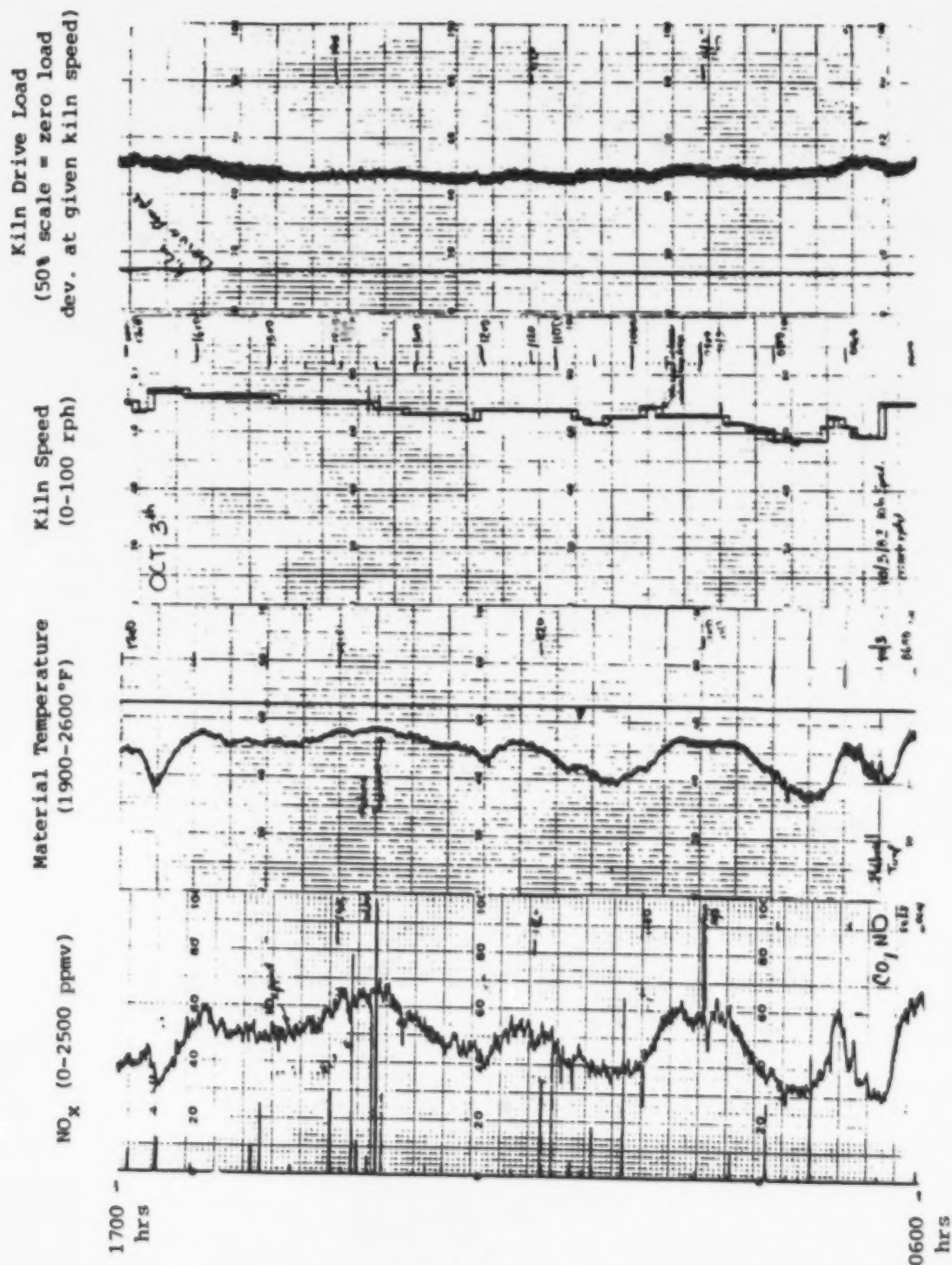


Figure E-16. Oct. 3 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

Kiln End Housing Press.
 (0-2" H₂O Neg.)
 Kiln Hood Pressure
 (±5" H₂O)
 Kiln Chain Temp.
 (800-1800°F)
 Undergrate Pressure
 (0-15" H₂O)

O₂, Dry (0-5%)

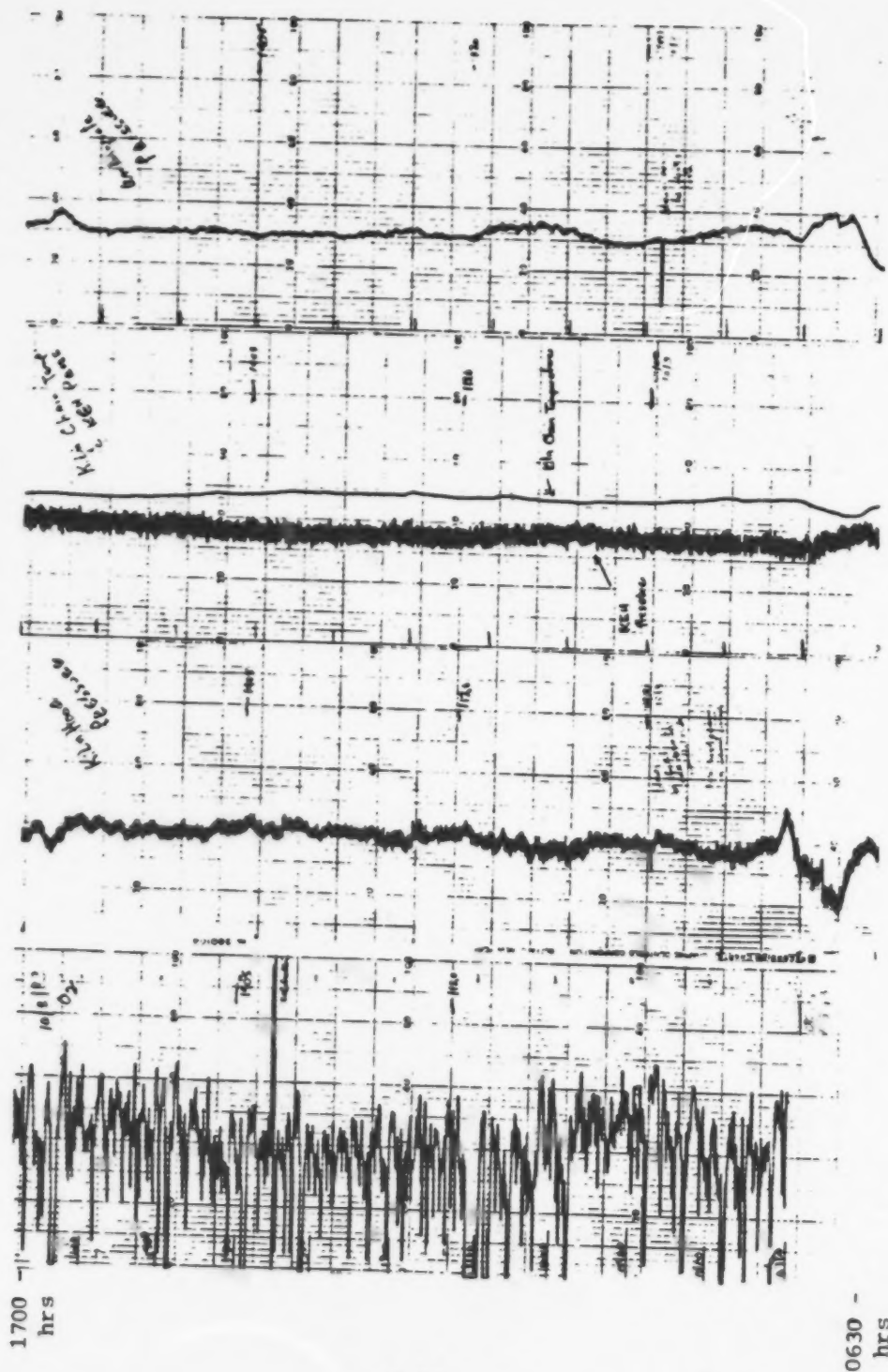


Figure E-17. Oct. 3 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

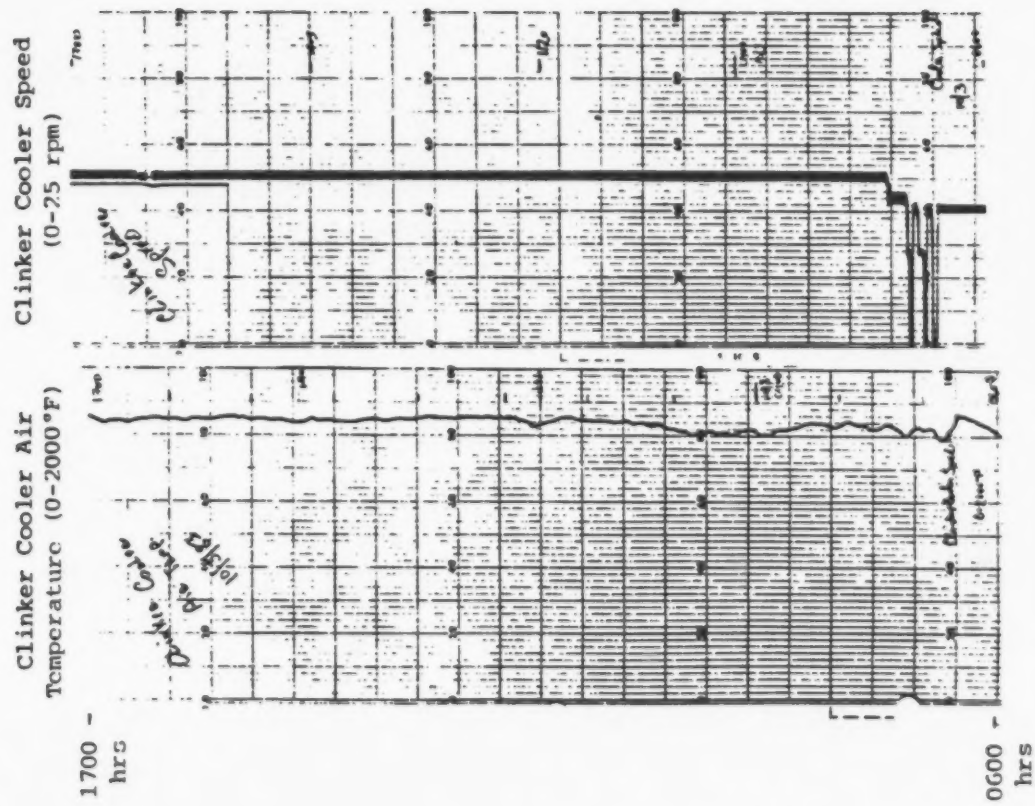


Figure E-18. Oct. 3 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

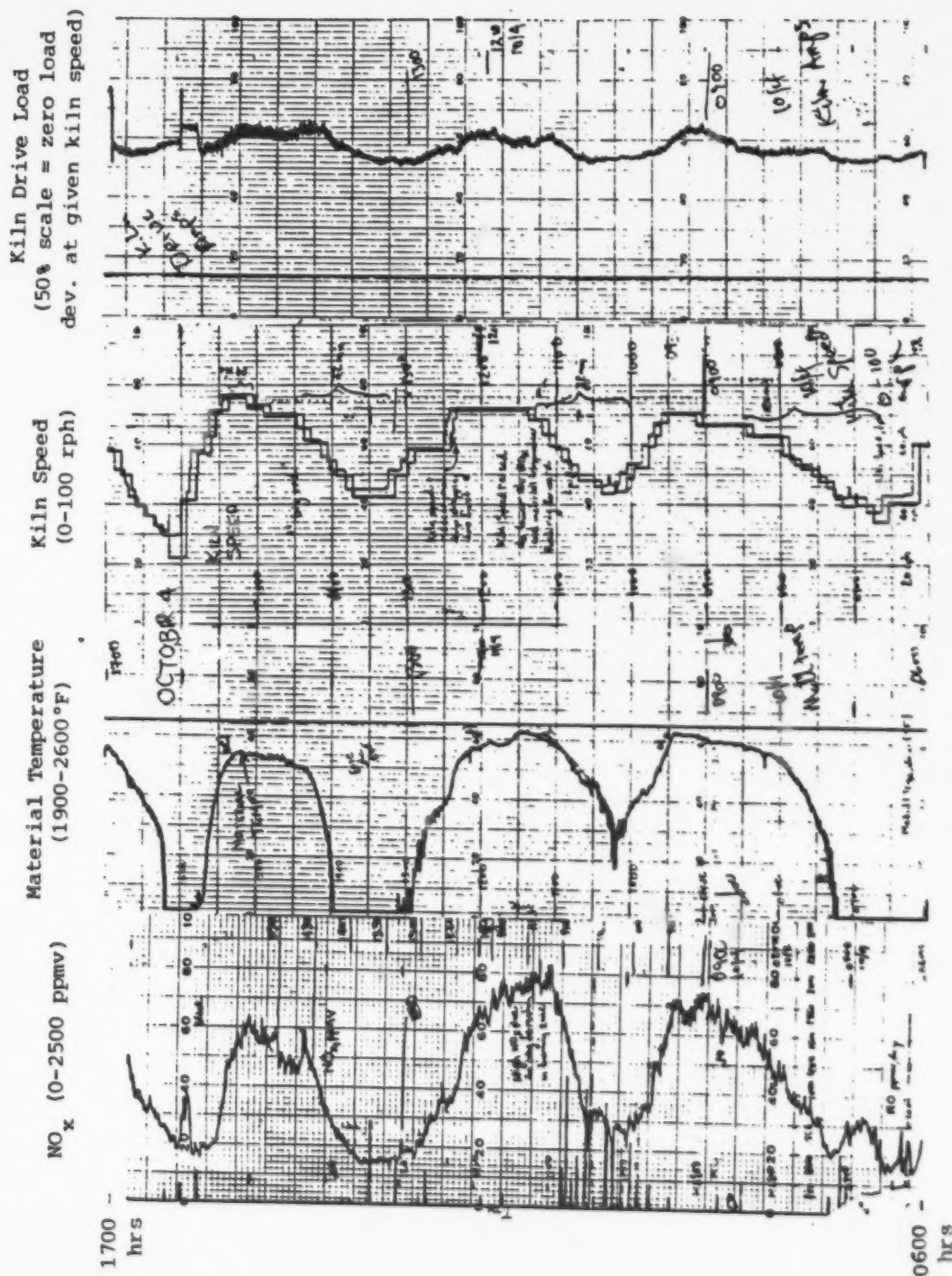


Figure E-19. Oct. 4 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

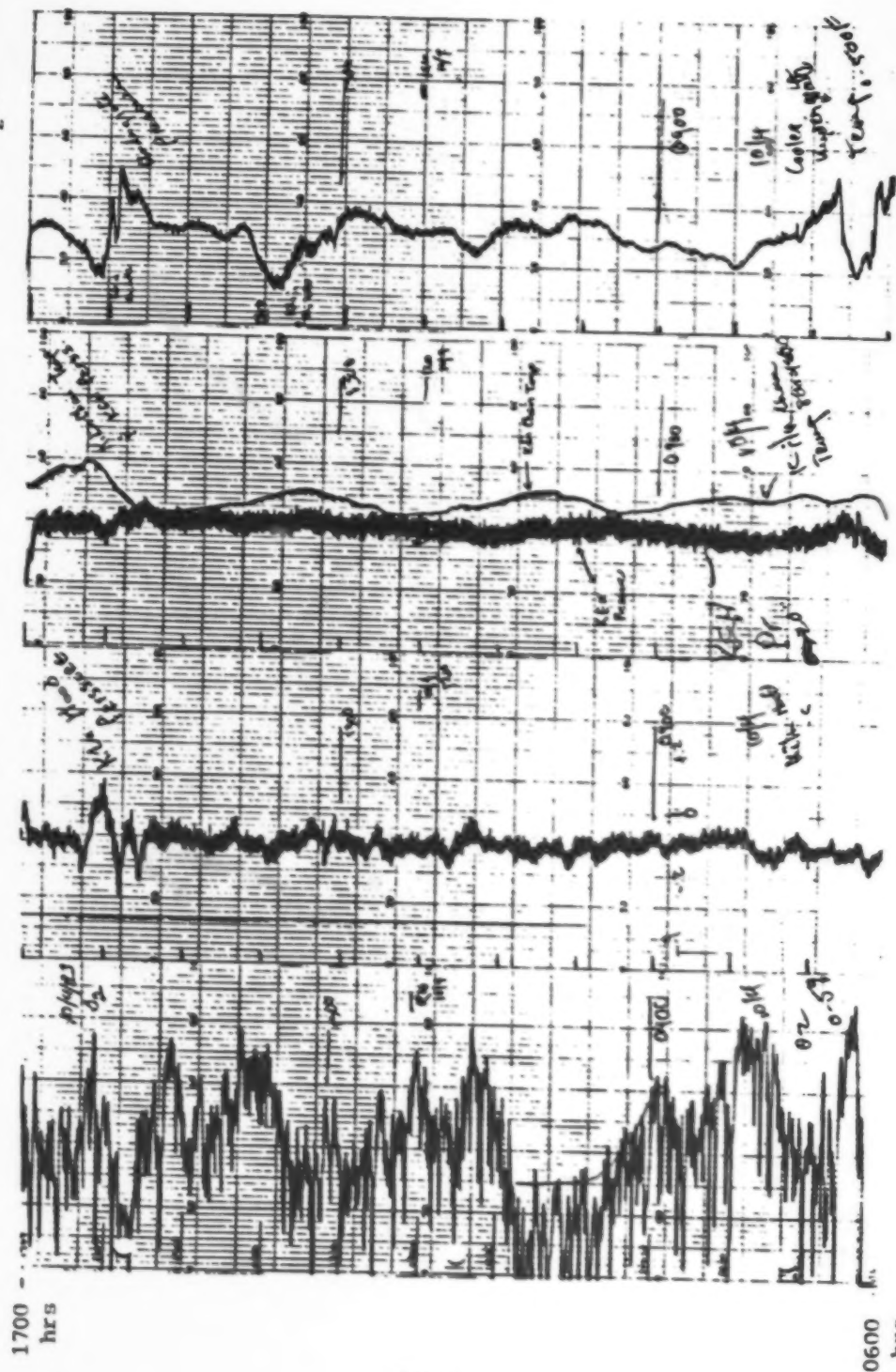


Figure E-20. Oct. 4 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

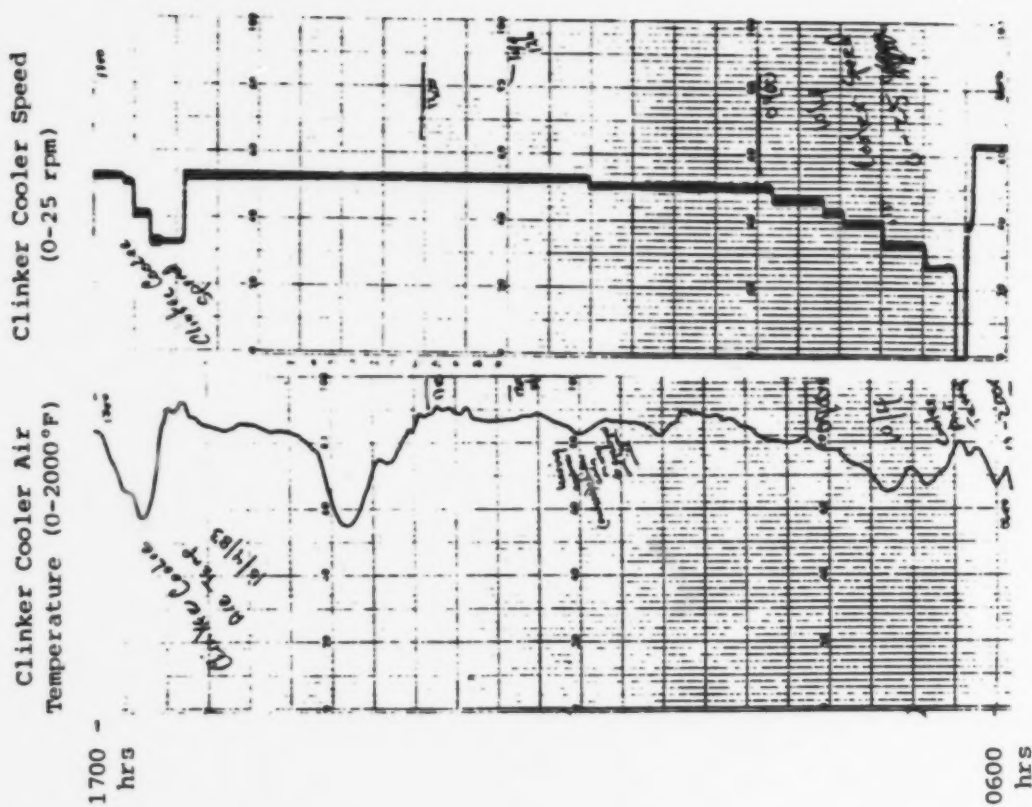


Figure E-21. Oct. 4 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

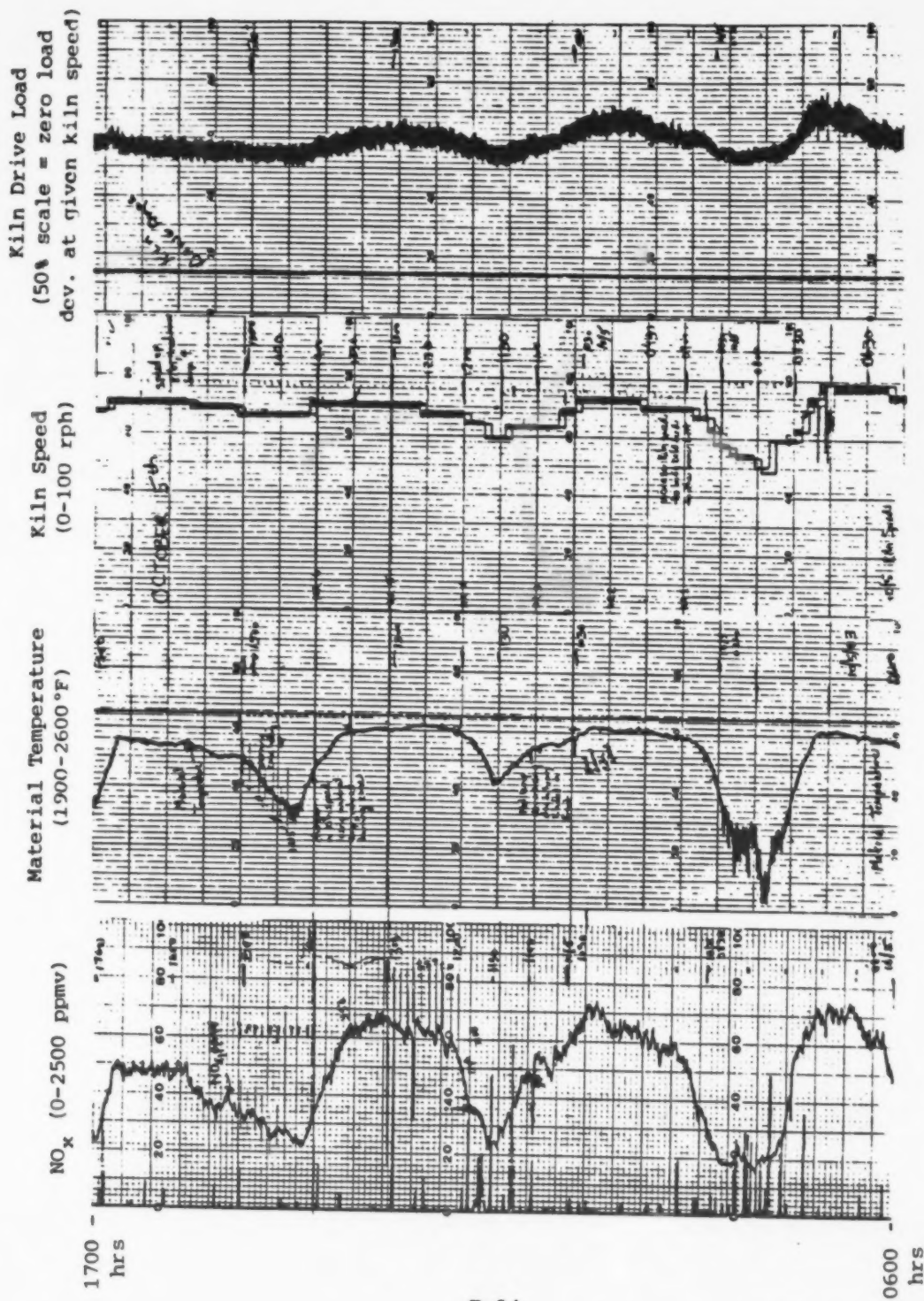


Figure E-22. Oct. 5 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

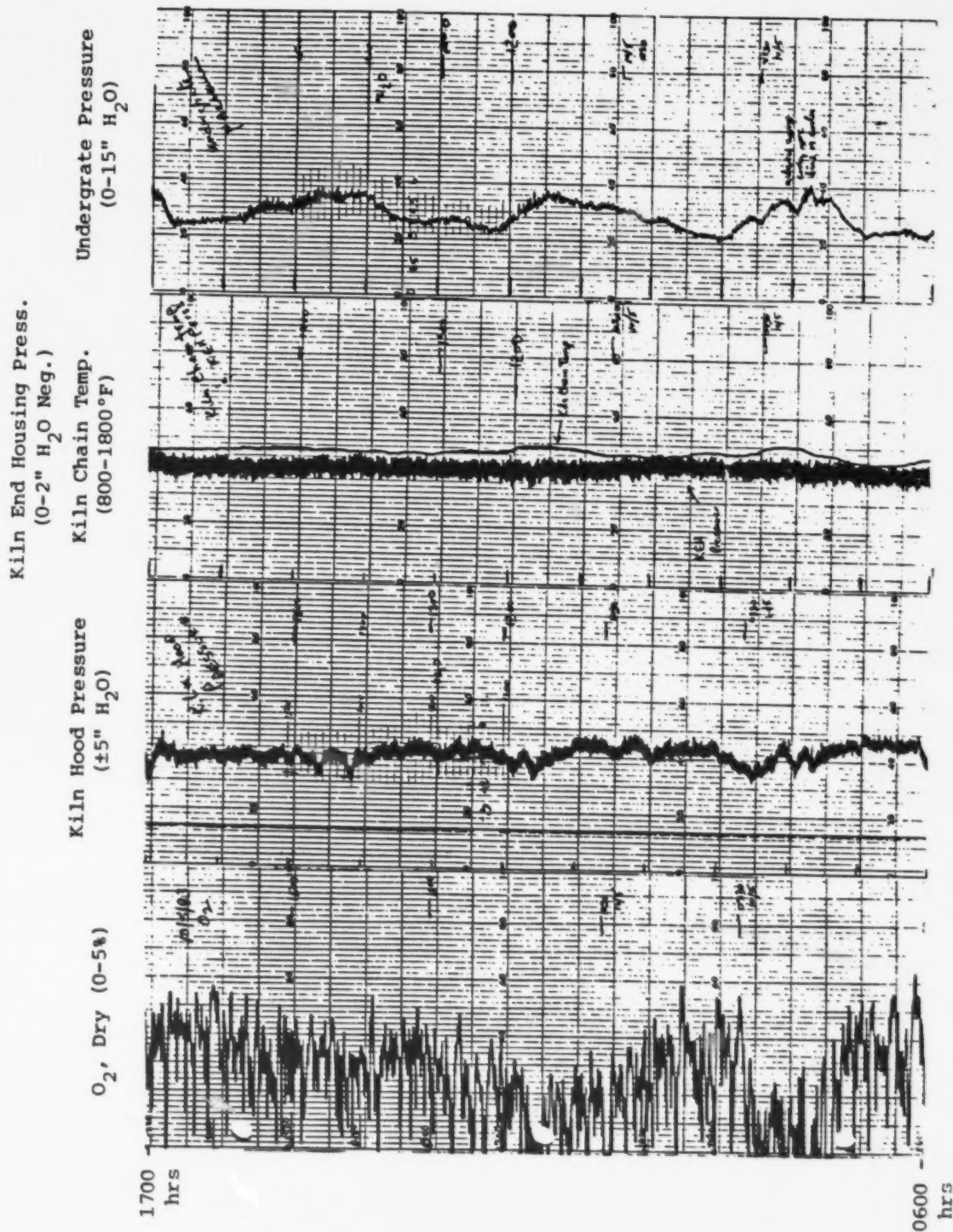


Figure E-23. Oct. 5 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

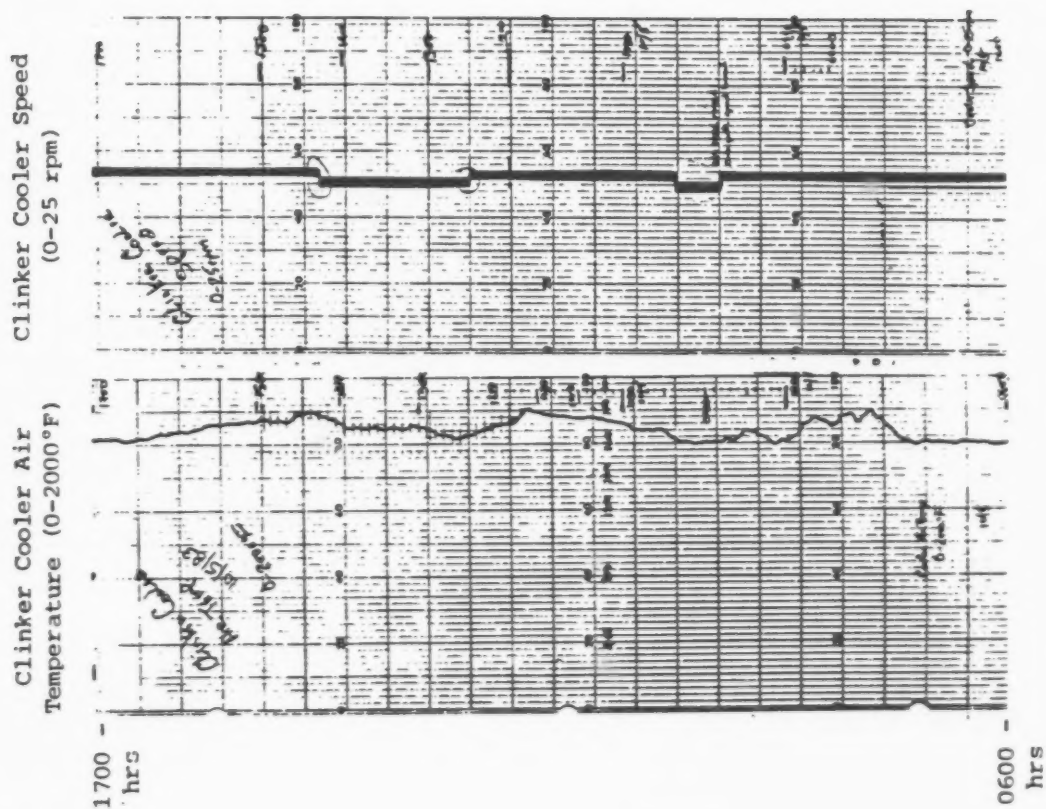


Figure E-24. Oct. 5 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

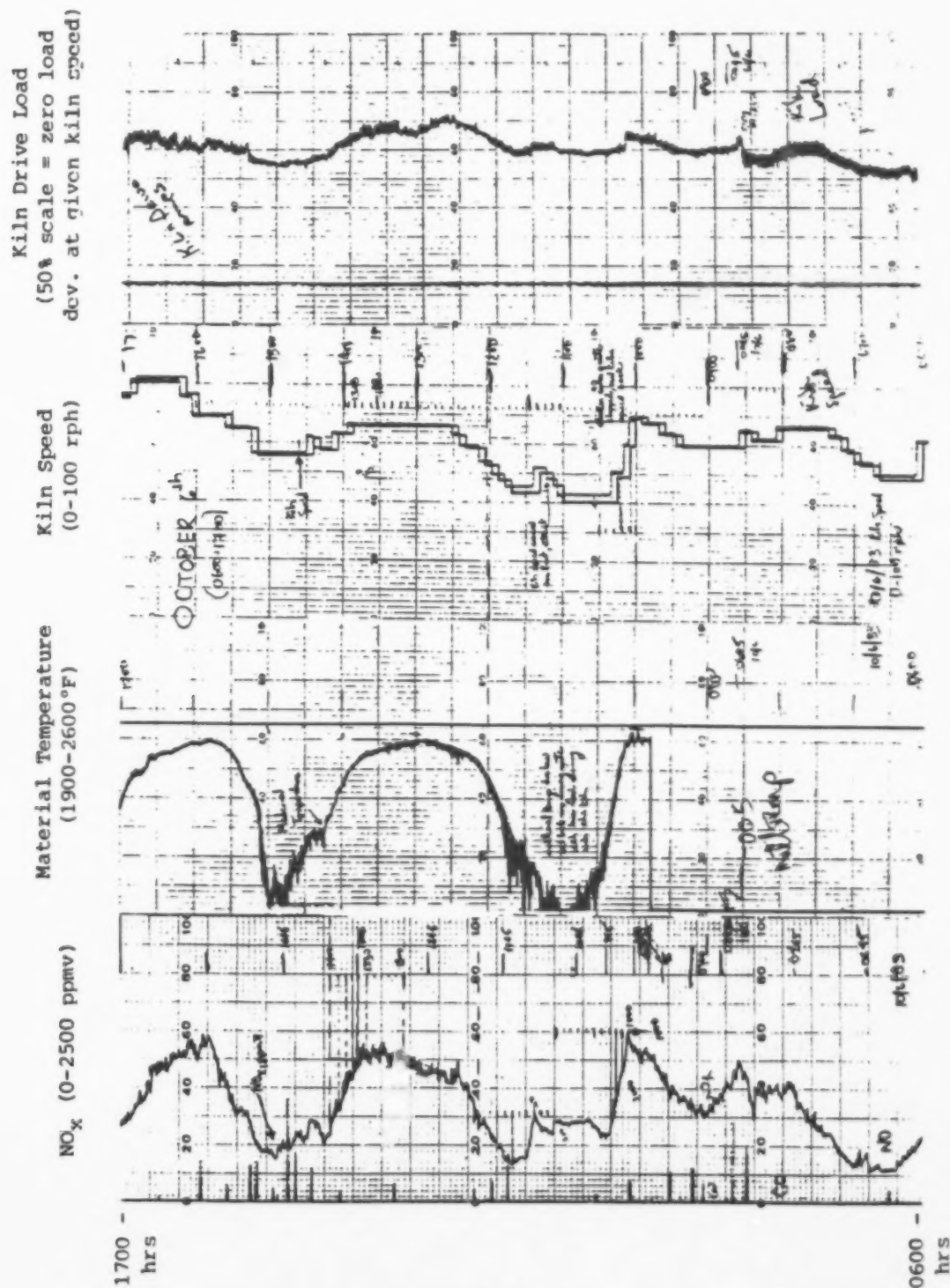


Figure E-25. Oct. 6 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

Kiln End Housing Press.

(0-2" H₂O Neg.)

Kiln Hood Pressure
(±5" H₂O)

Kiln Chain Temp.
(800-1800°F)

Undergrate Pressure
(0-15" H₂O)

O₂, Dry (0-5%)

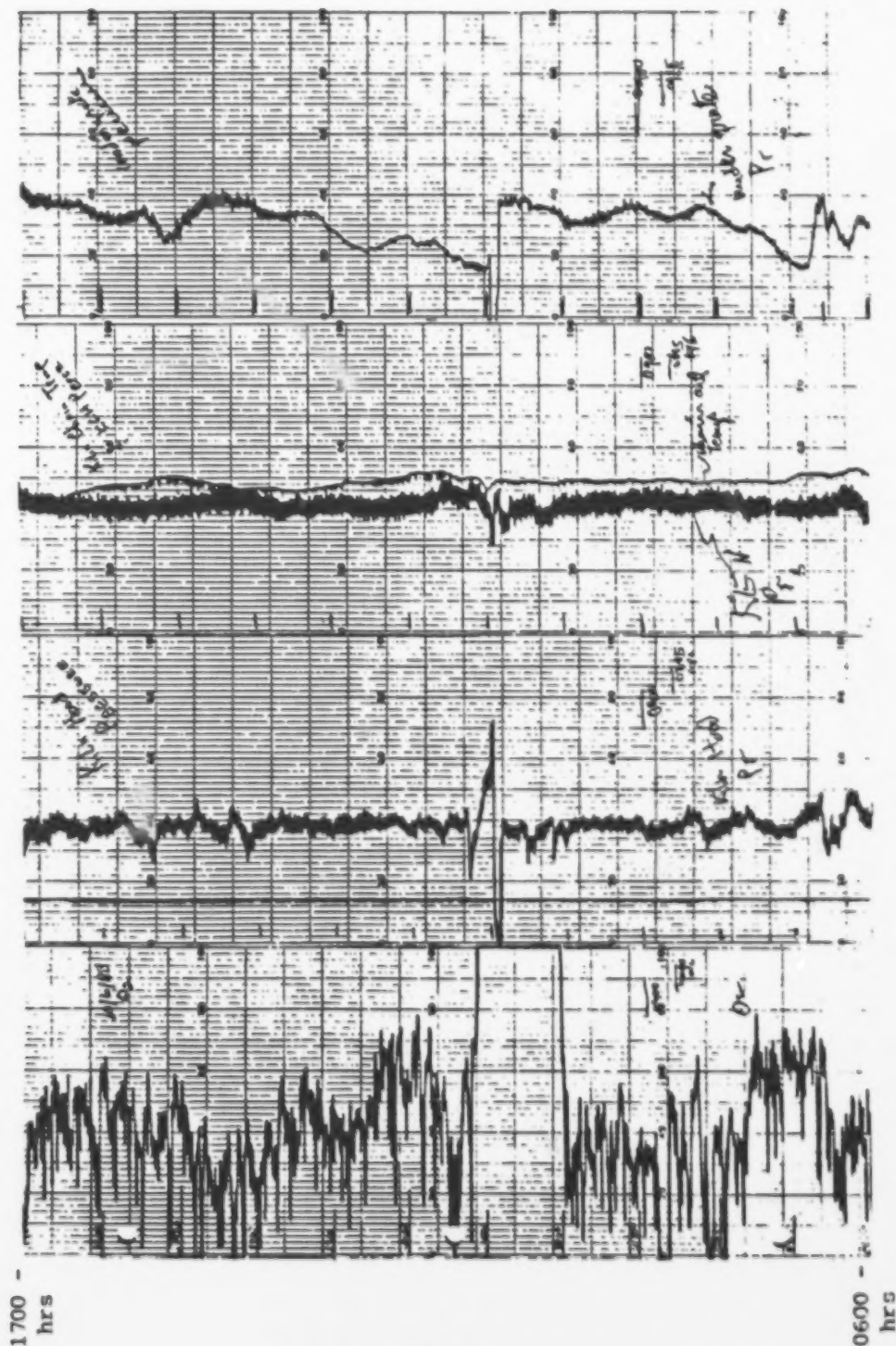


Figure E-26. Oct. 6 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

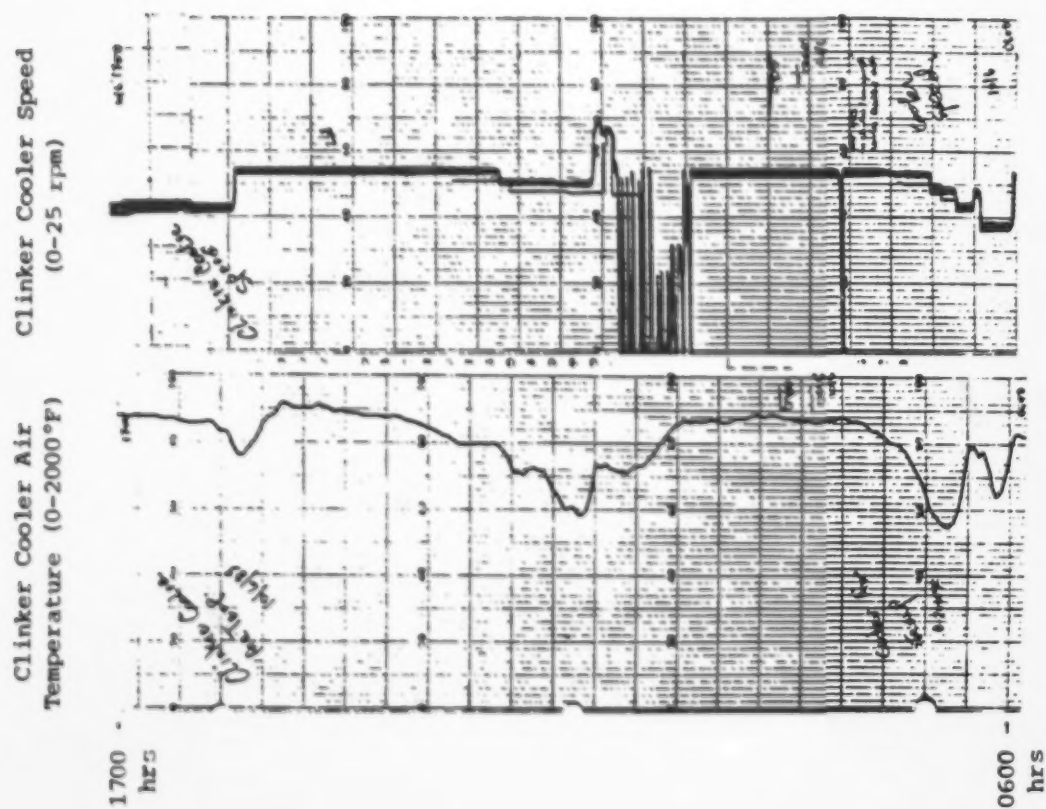


Figure E-27. Oct. 6 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

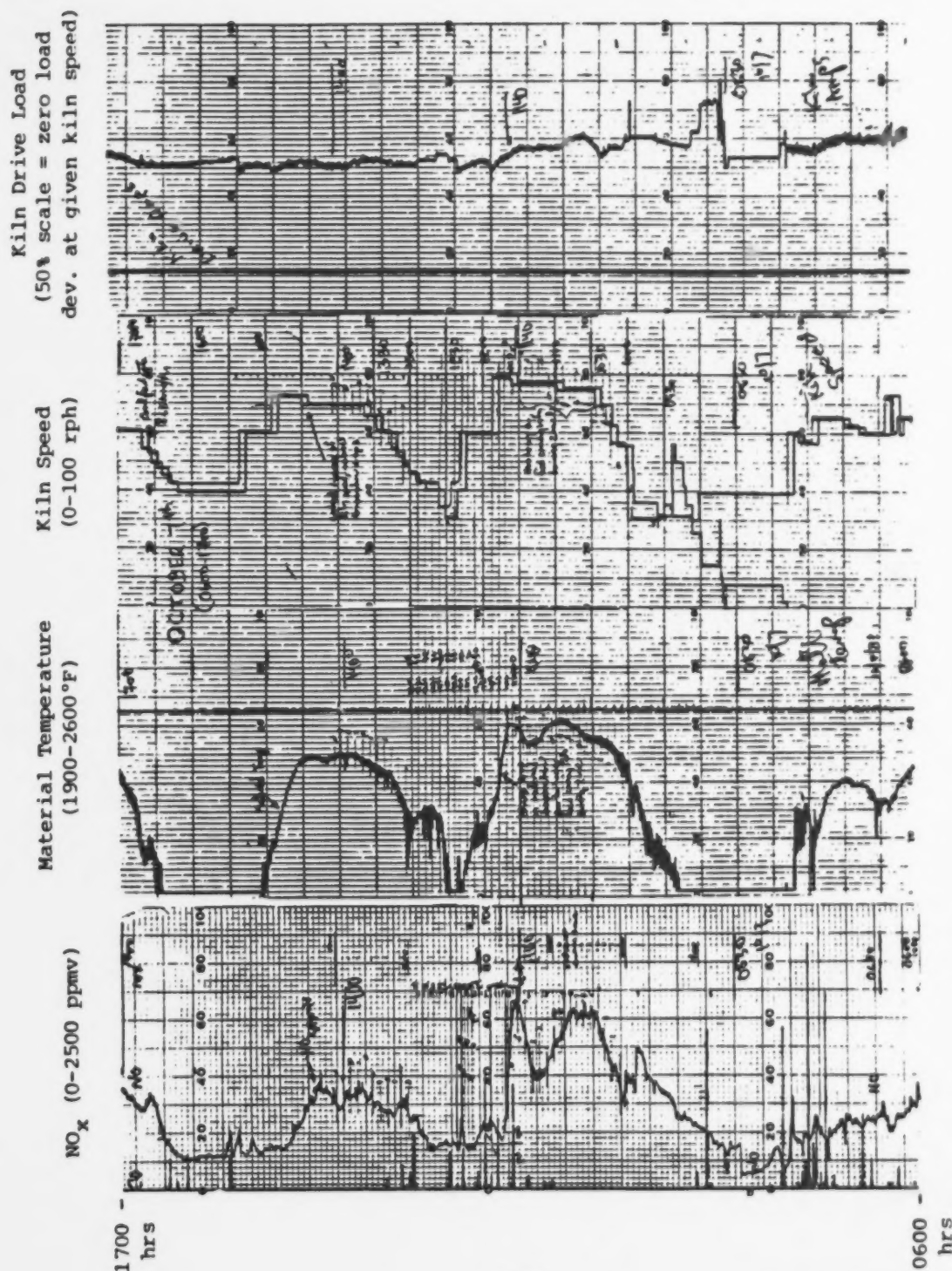


Figure E-28. Oct. 7 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

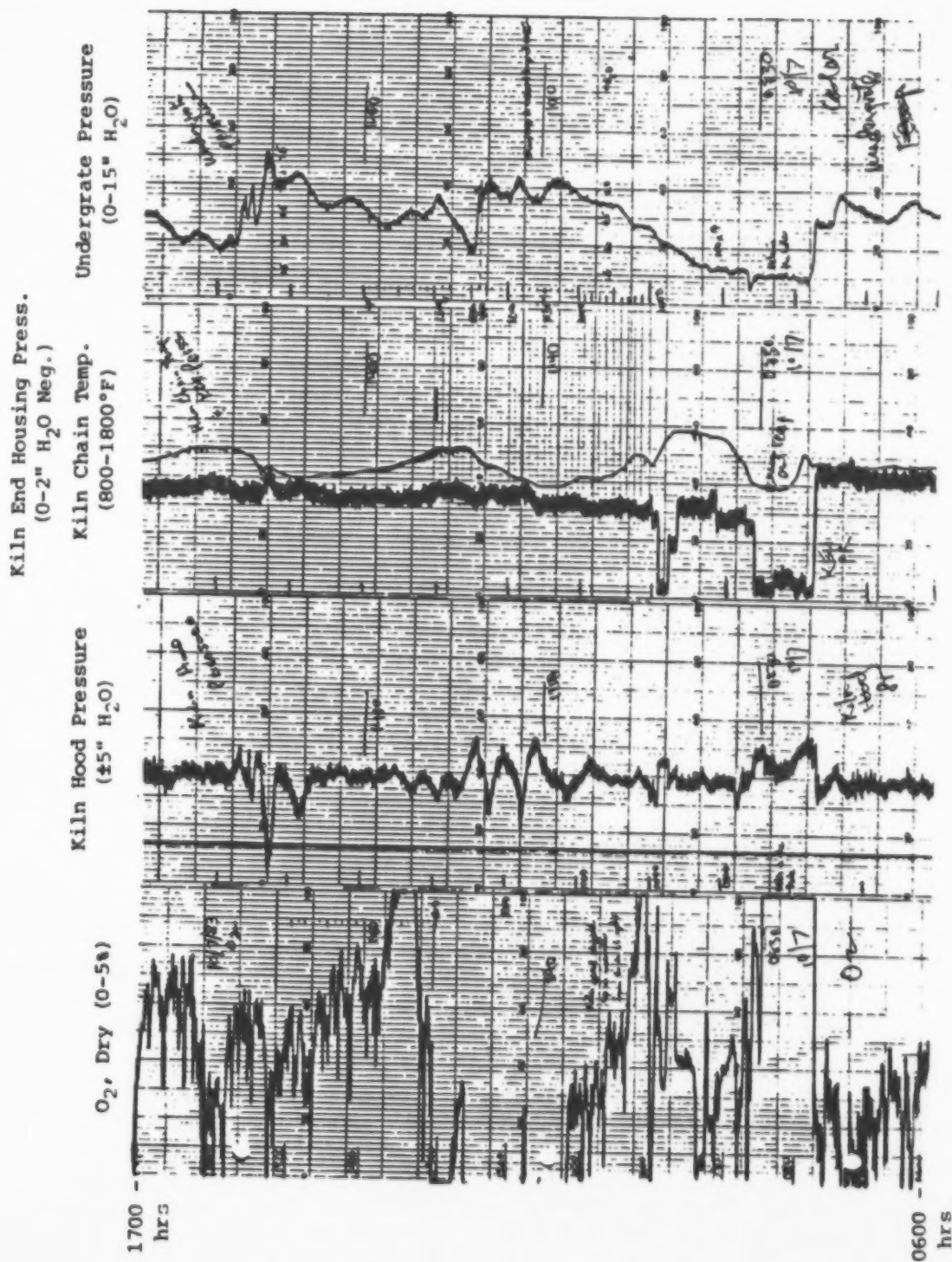


Figure E-29. Oct. 7 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

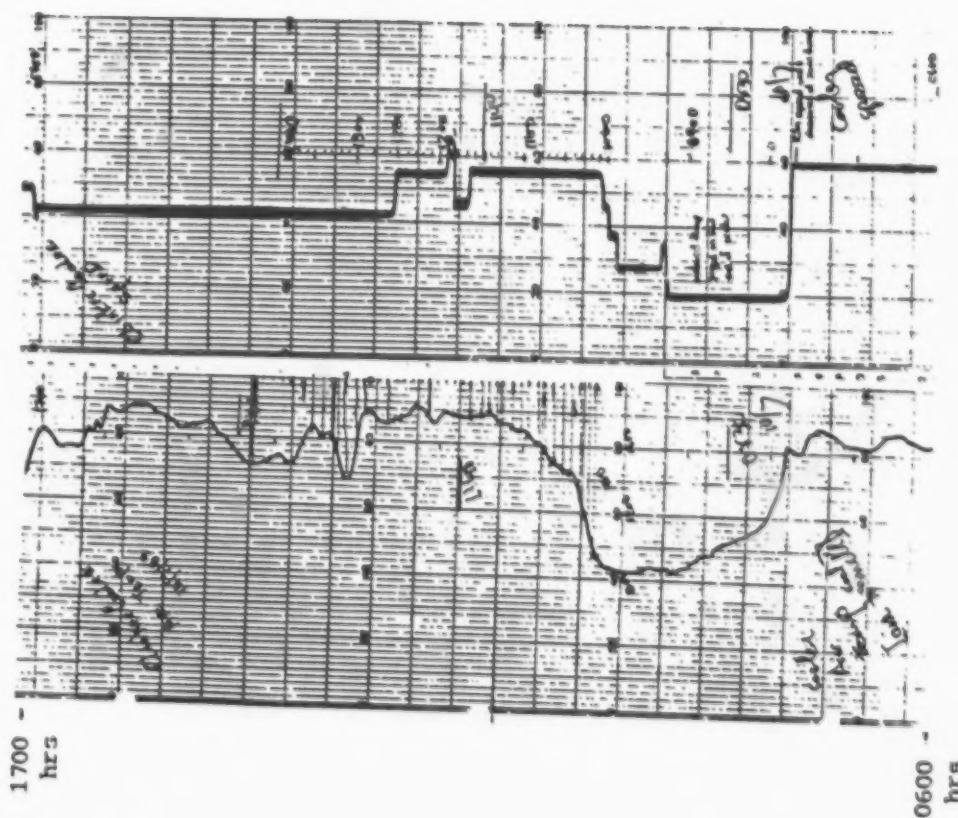


Figure E-30. Oct. 10 (Clinker Cooler Air Temp., Clinker Cooler Speed);
0600-1700 hrs

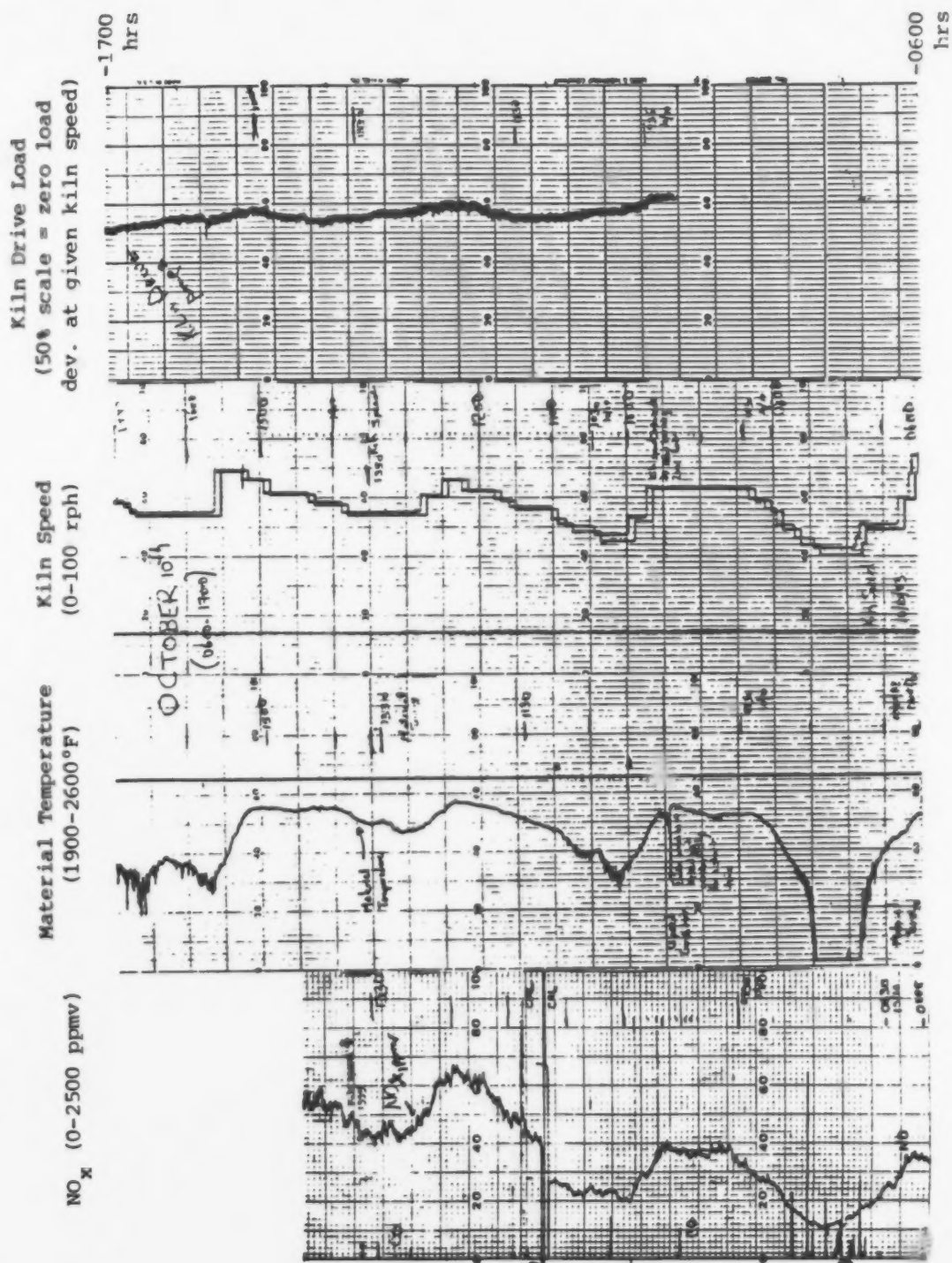


Figure E-31. Oct. 10 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

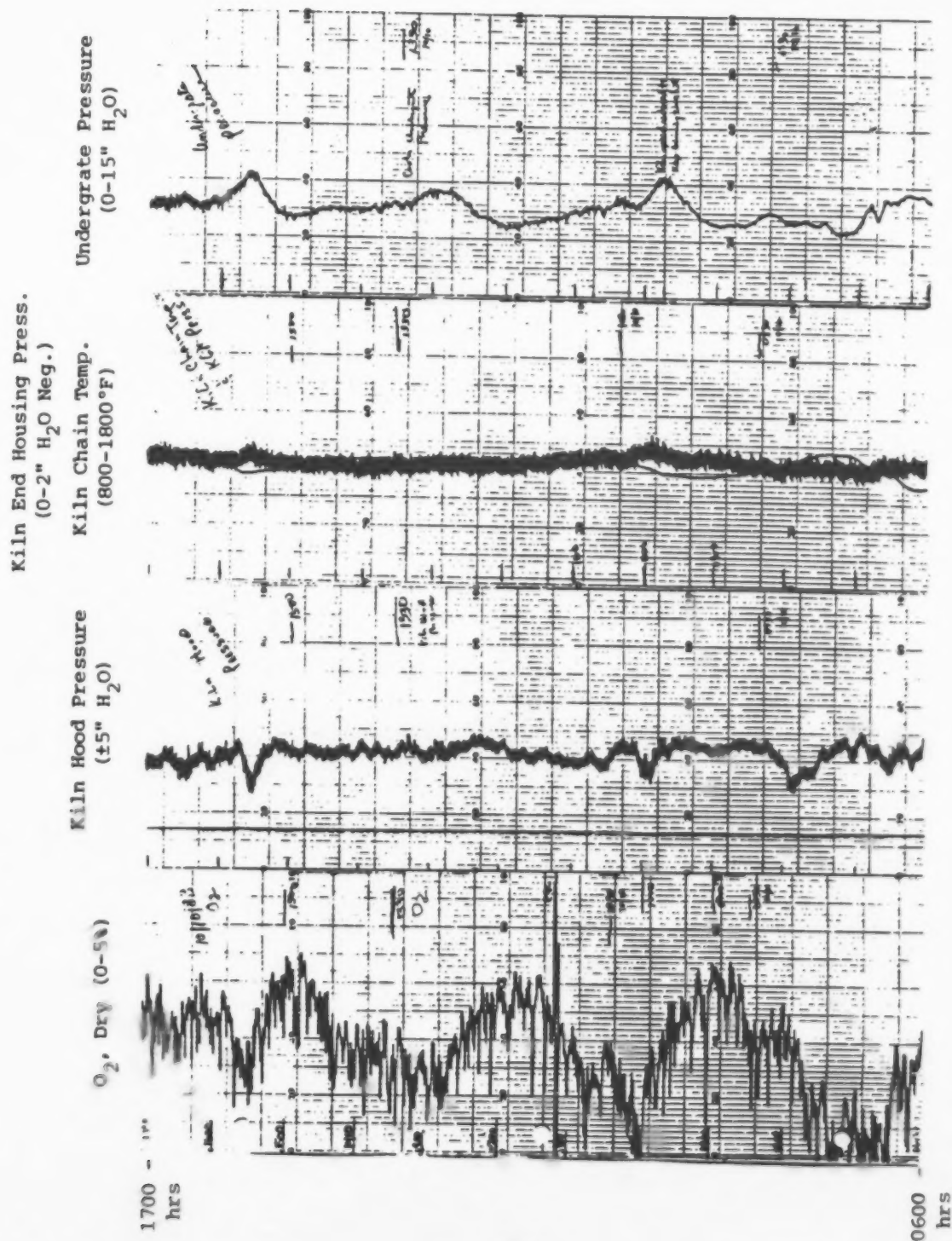


Figure E-32. Oct. 10 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

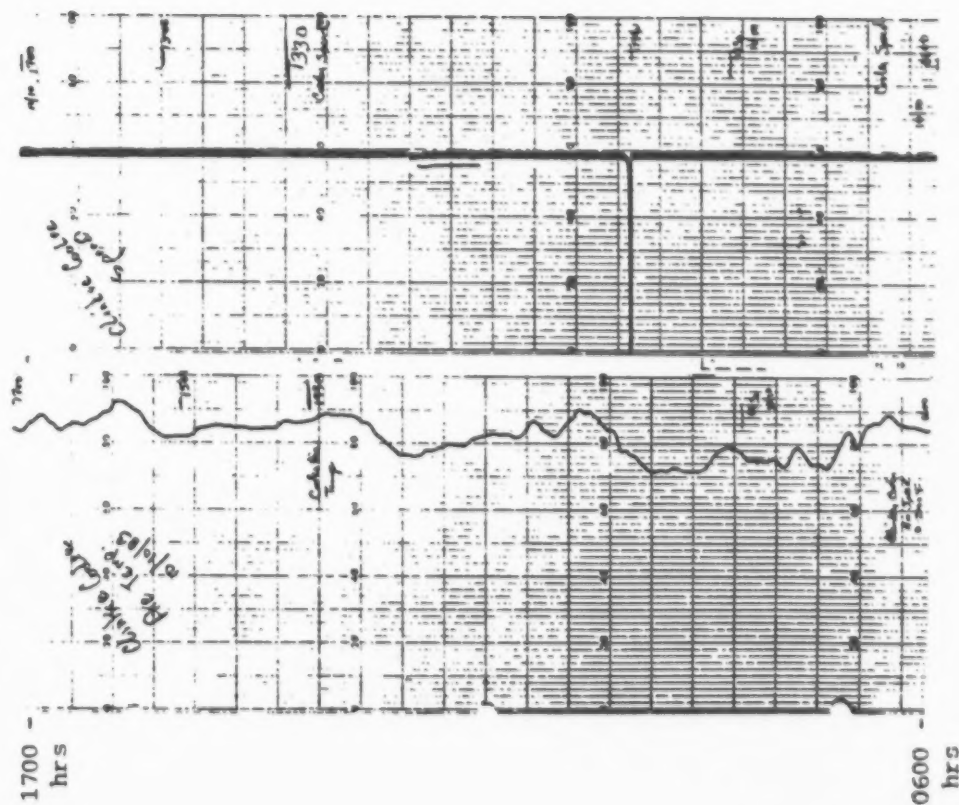


Figure E-33. Oct. 10 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

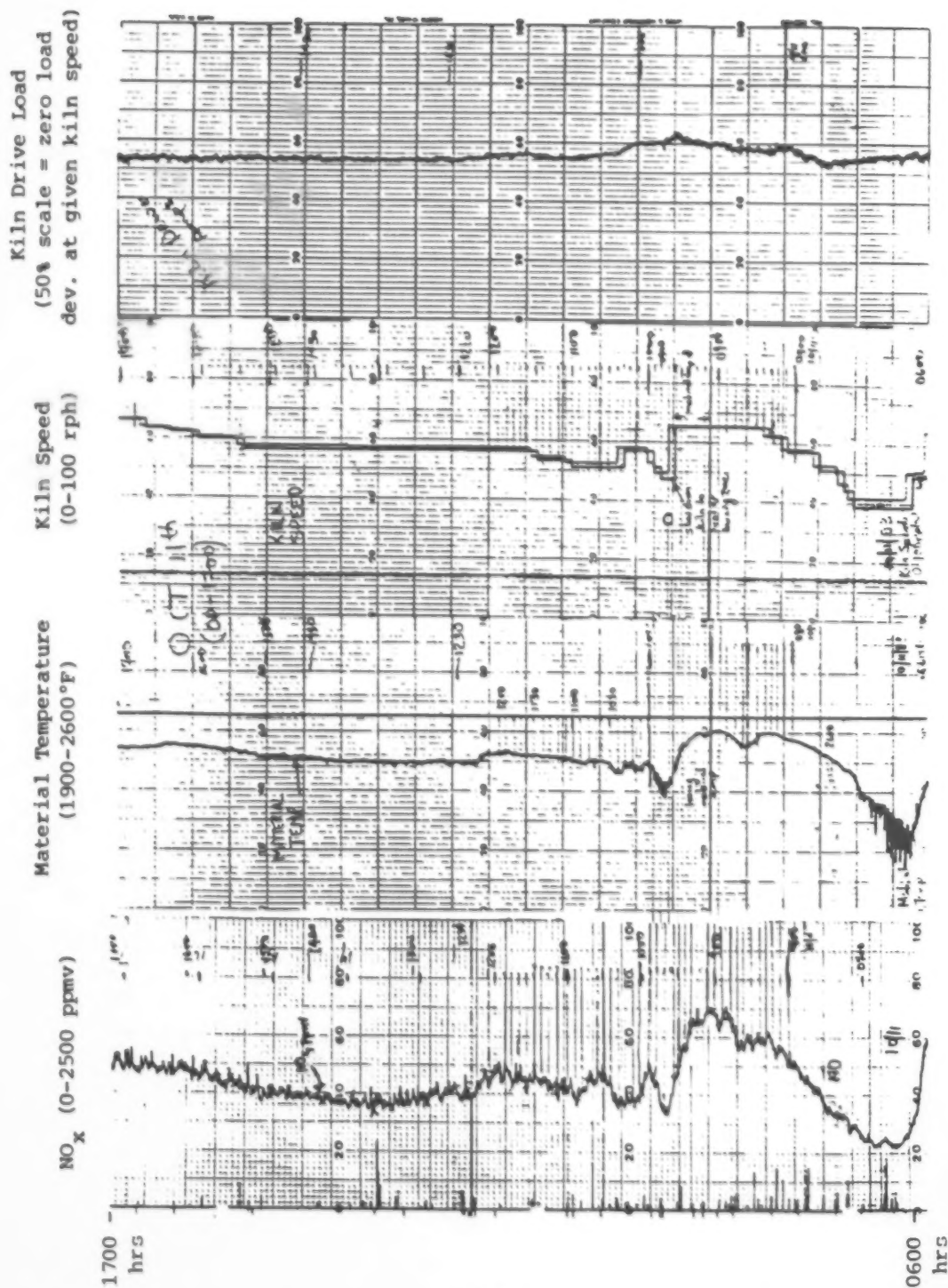


Figure E-34. Oct. 11 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

Kiln End Housing Press.
(0-2" H₂O Neg.)

Kiln Hood Pressure
(±5" H₂O)

Undergrate Pressure
(0-15" H₂O)

O₂, Dry (0-5%)

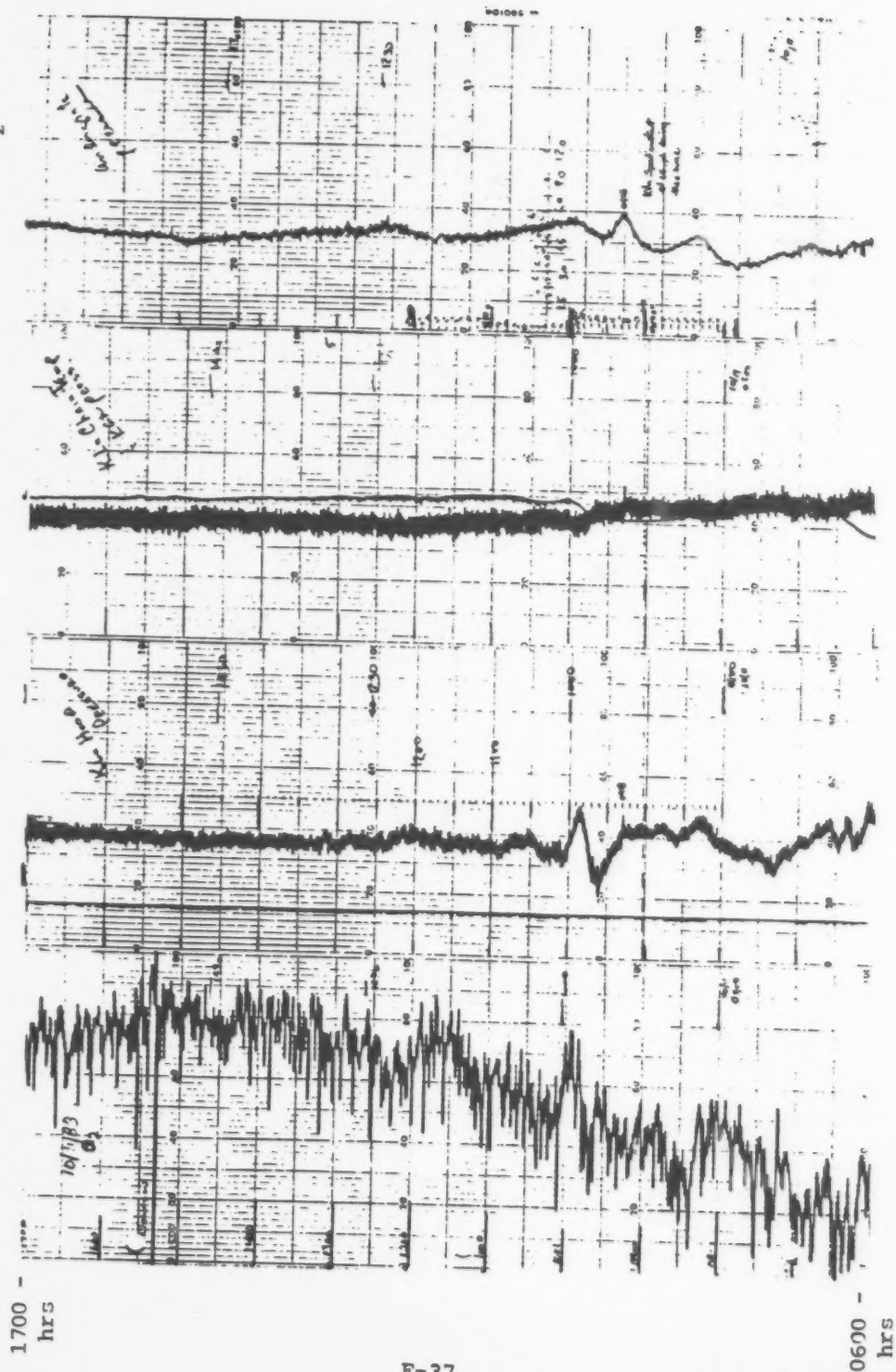


Figure E-35. Oct. 11 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

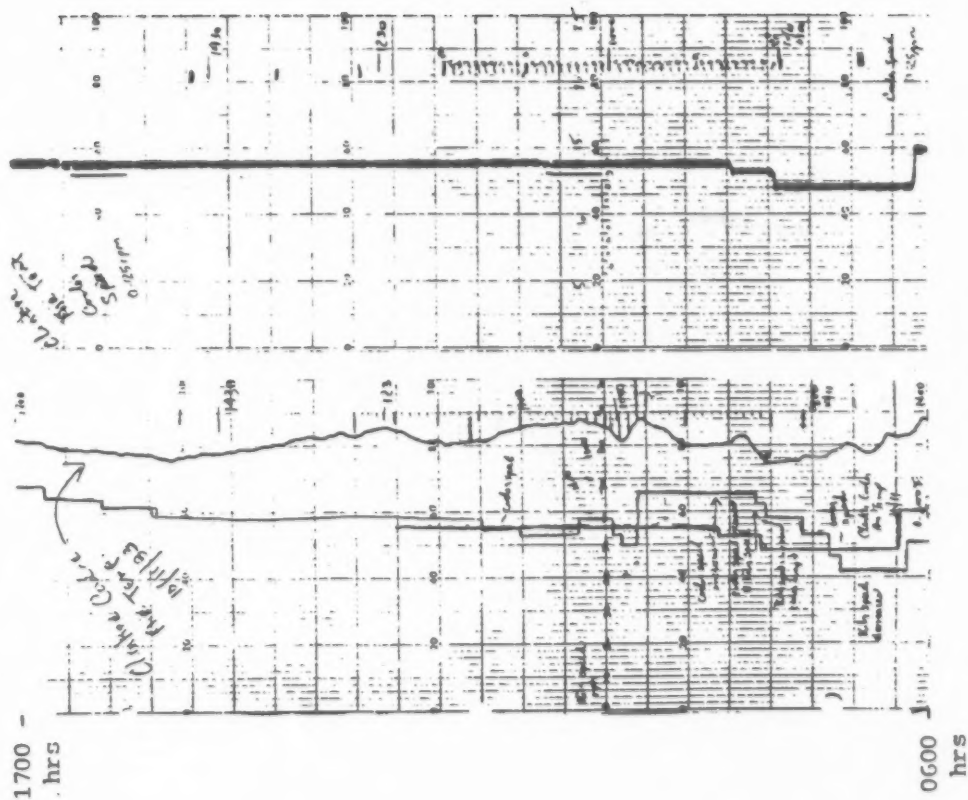


Figure E-36. Oct. 11 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

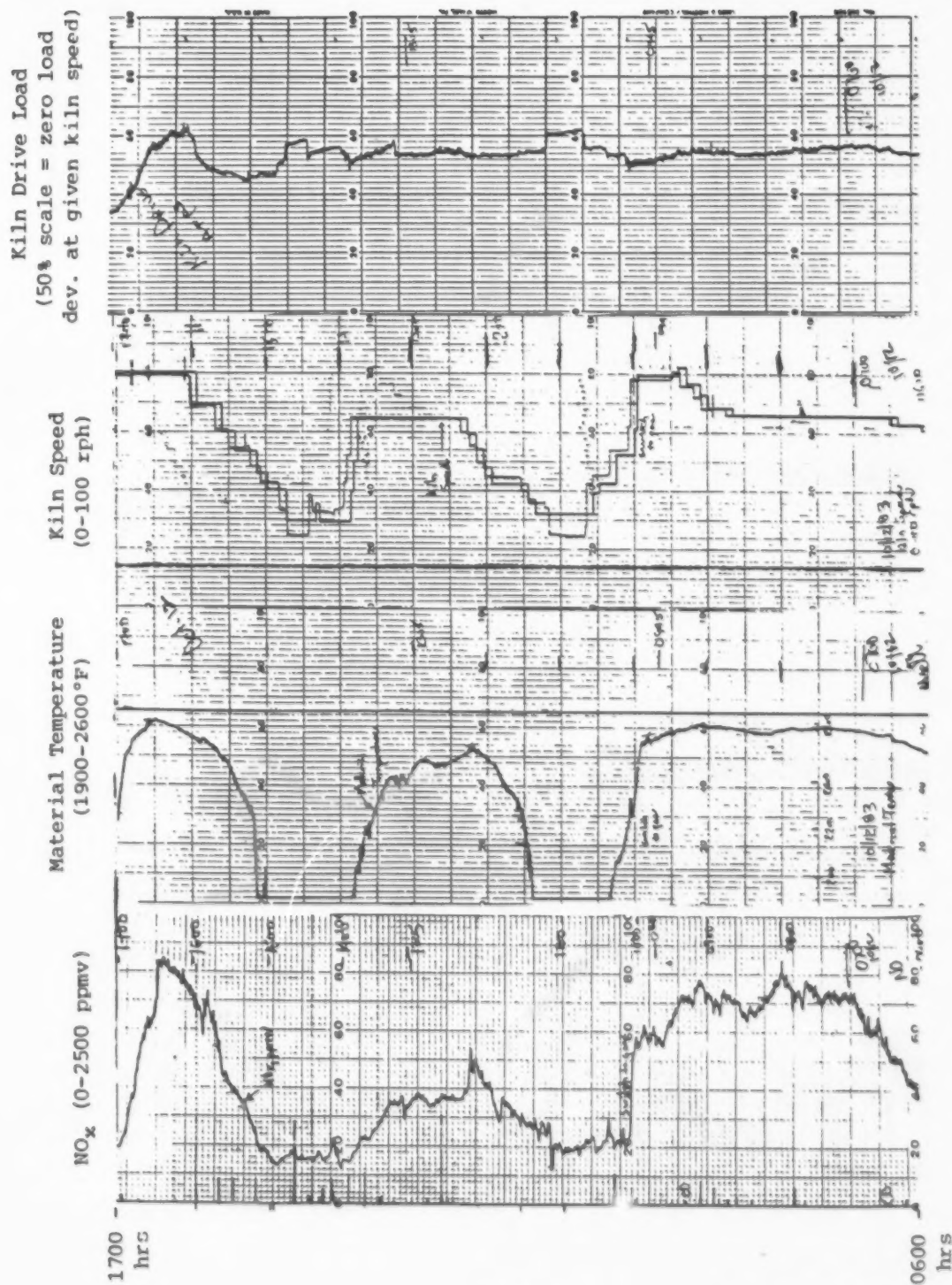


Figure E-37. Oct. 12 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

Kiln End Housing Press.
(0-2" H₂O Neg.)

Kiln Chain Temp.
(800-1800 °F)

Kiln Hood Pressure
(±5" H₂O)

Undergrate Pressure
(0-15" H₂O)

O₂, Dry (0-5%)

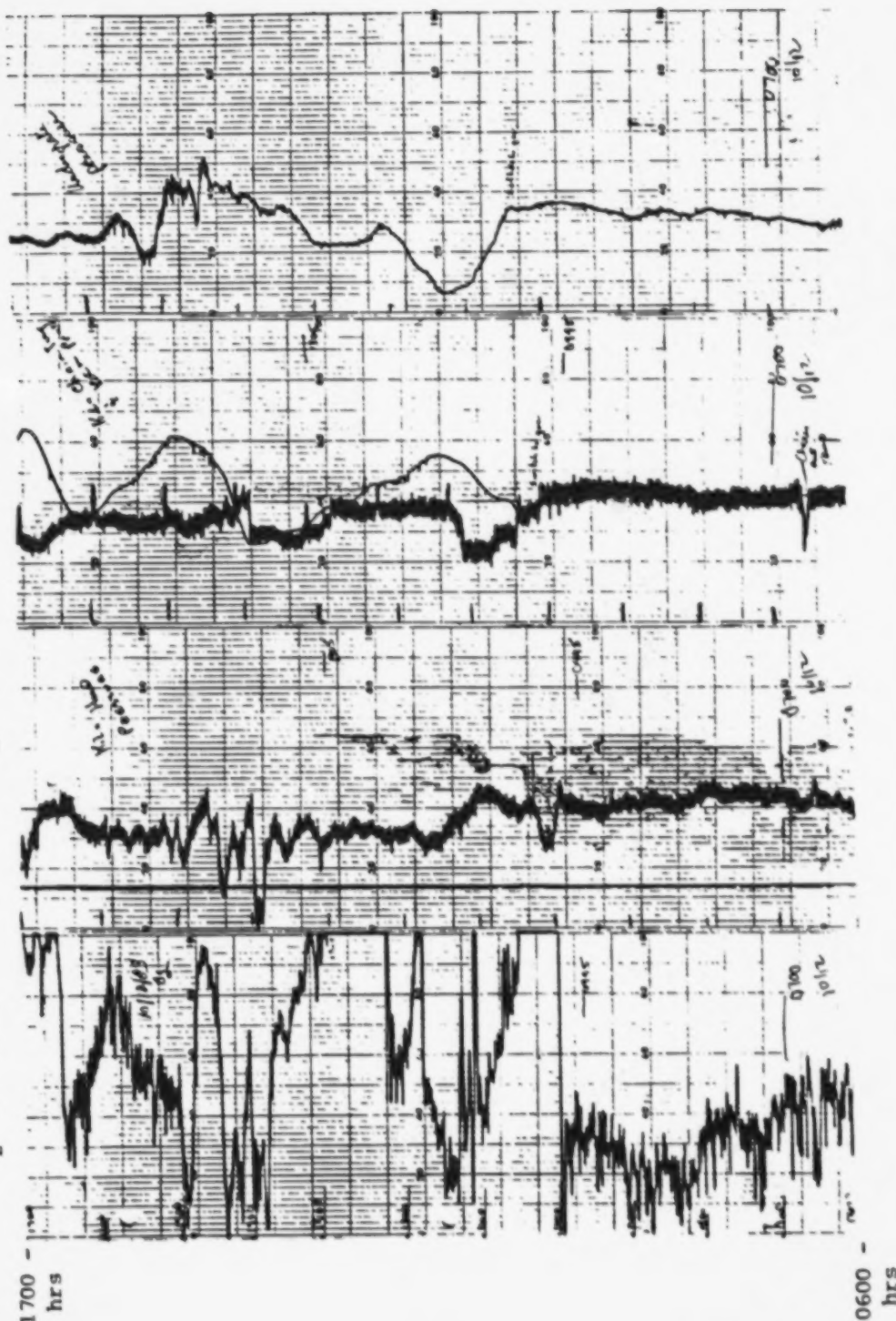


Figure E-38. Oct. 12 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Speed
(0-25 rpm)

Clinker Cooler Air
Temperature (0-2000°F)

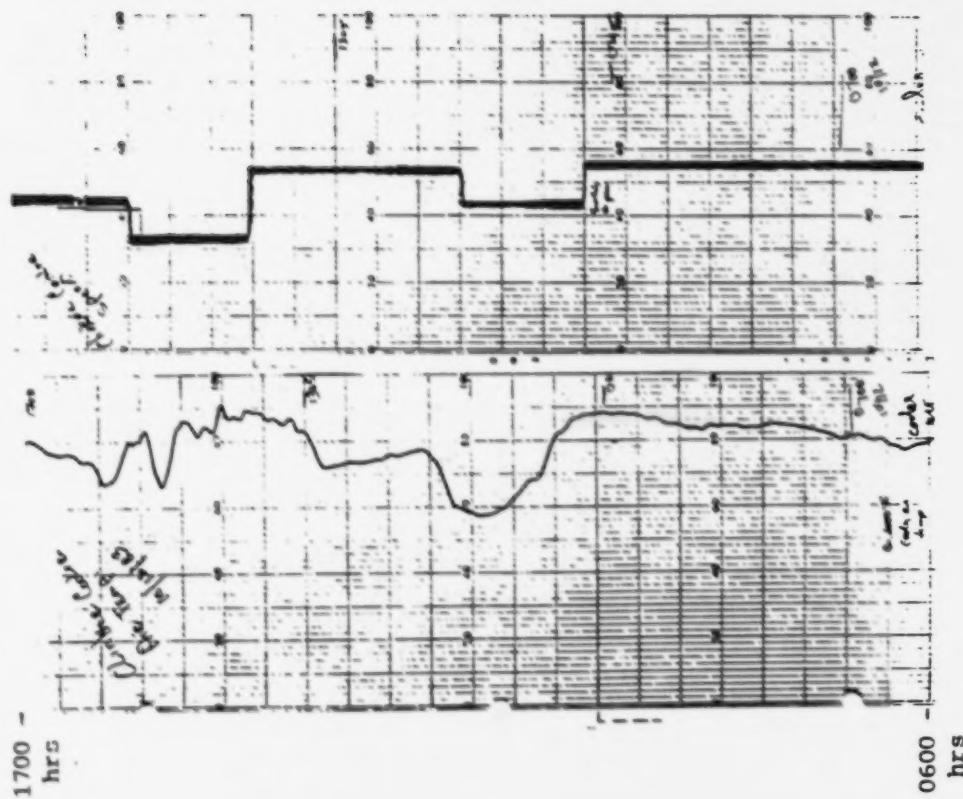


Figure E-39. Oct. 12 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

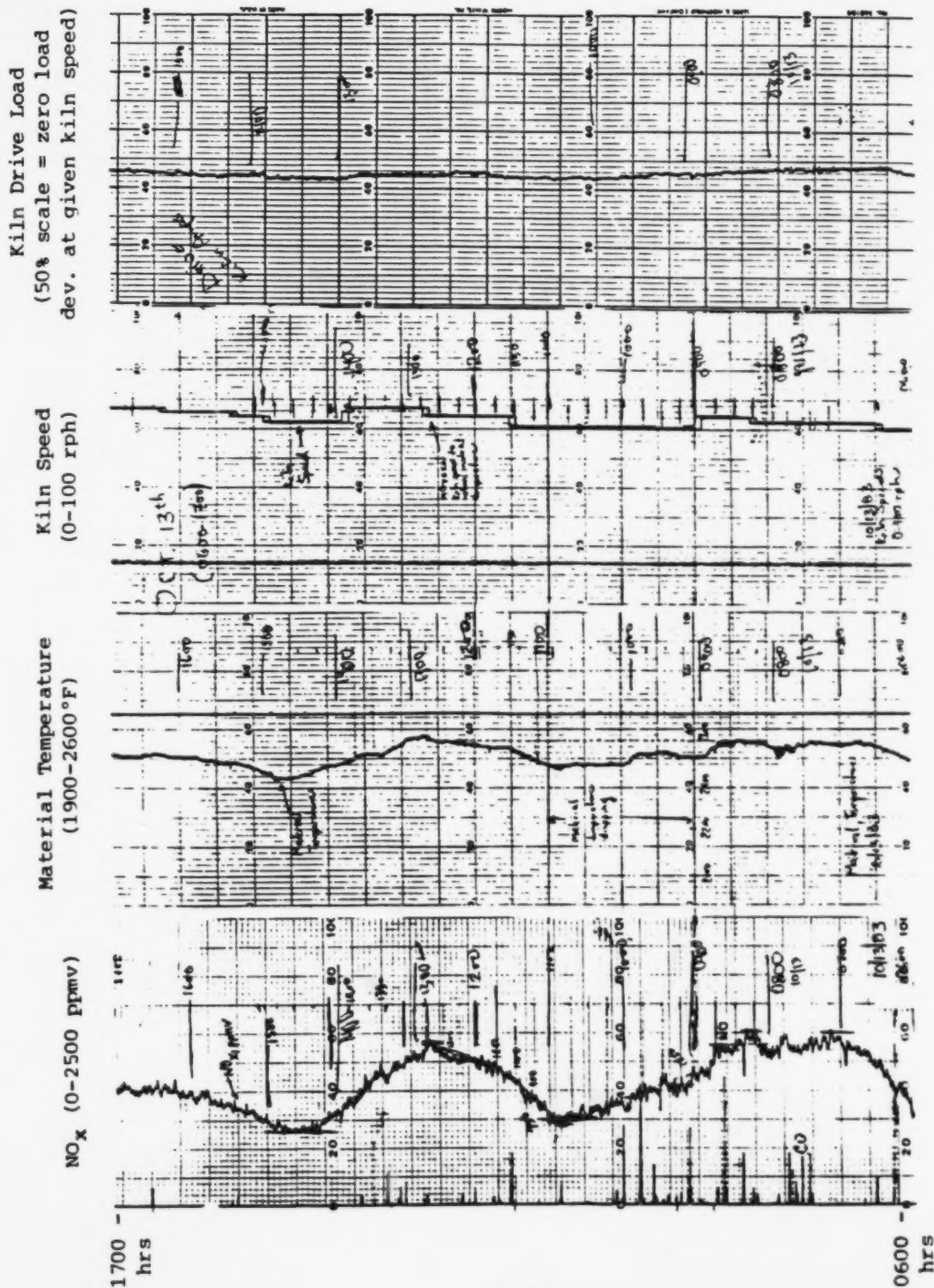


Figure E-40. Oct. 13 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

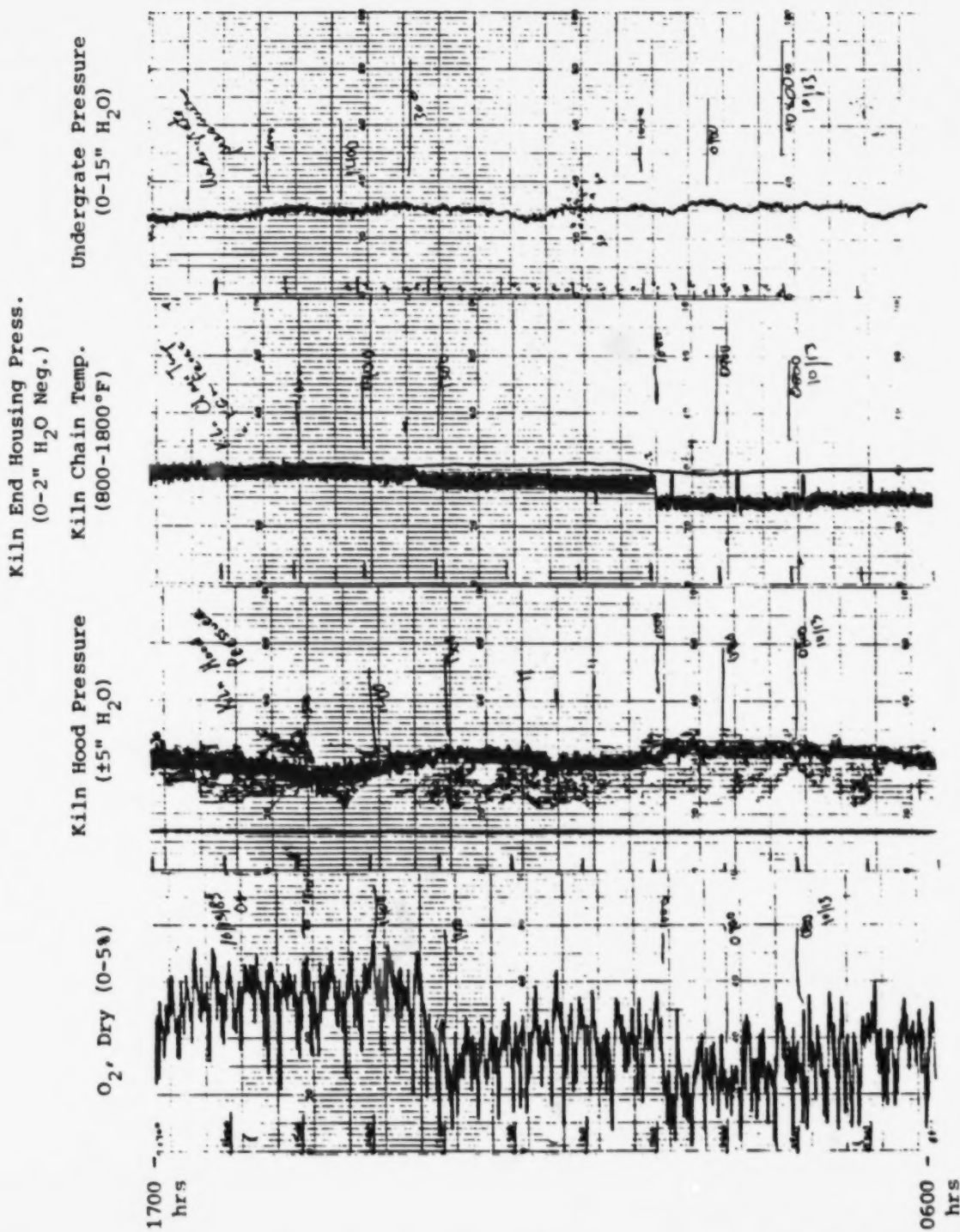


Figure E-41. Oct. 13 (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate pressure); 0600-1700 hrs

Clinker Cooler Speed
(0-25 rpm)

Clinker Cooler Air
Temperature (0-2000°F)

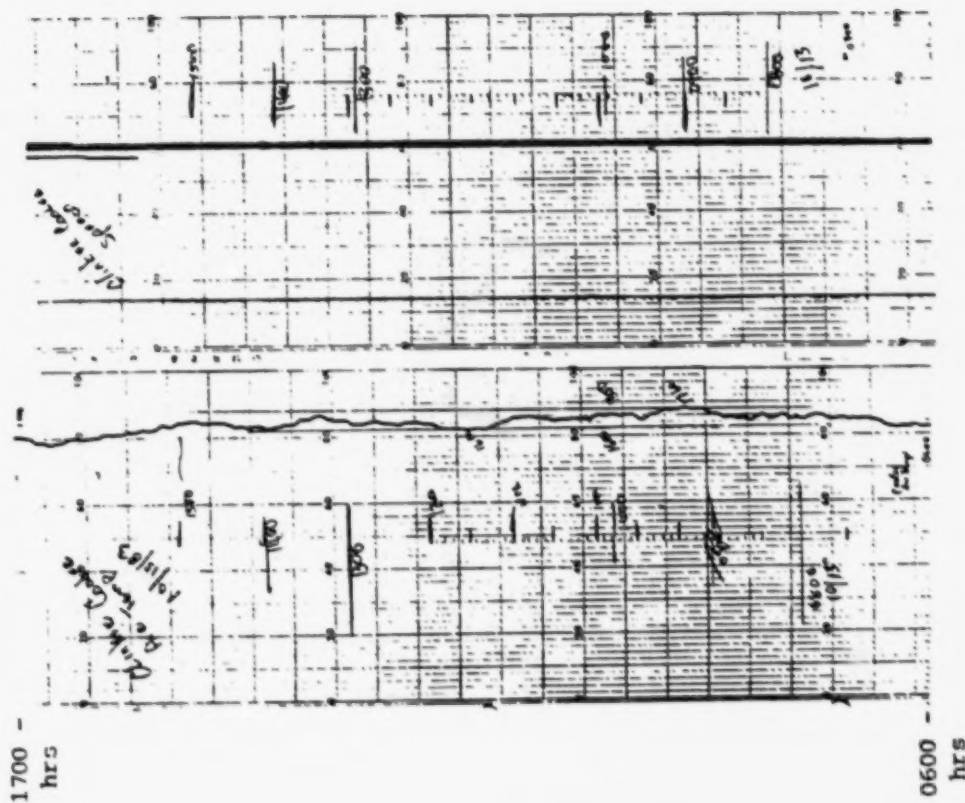


Figure E-42. Oct. 13 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

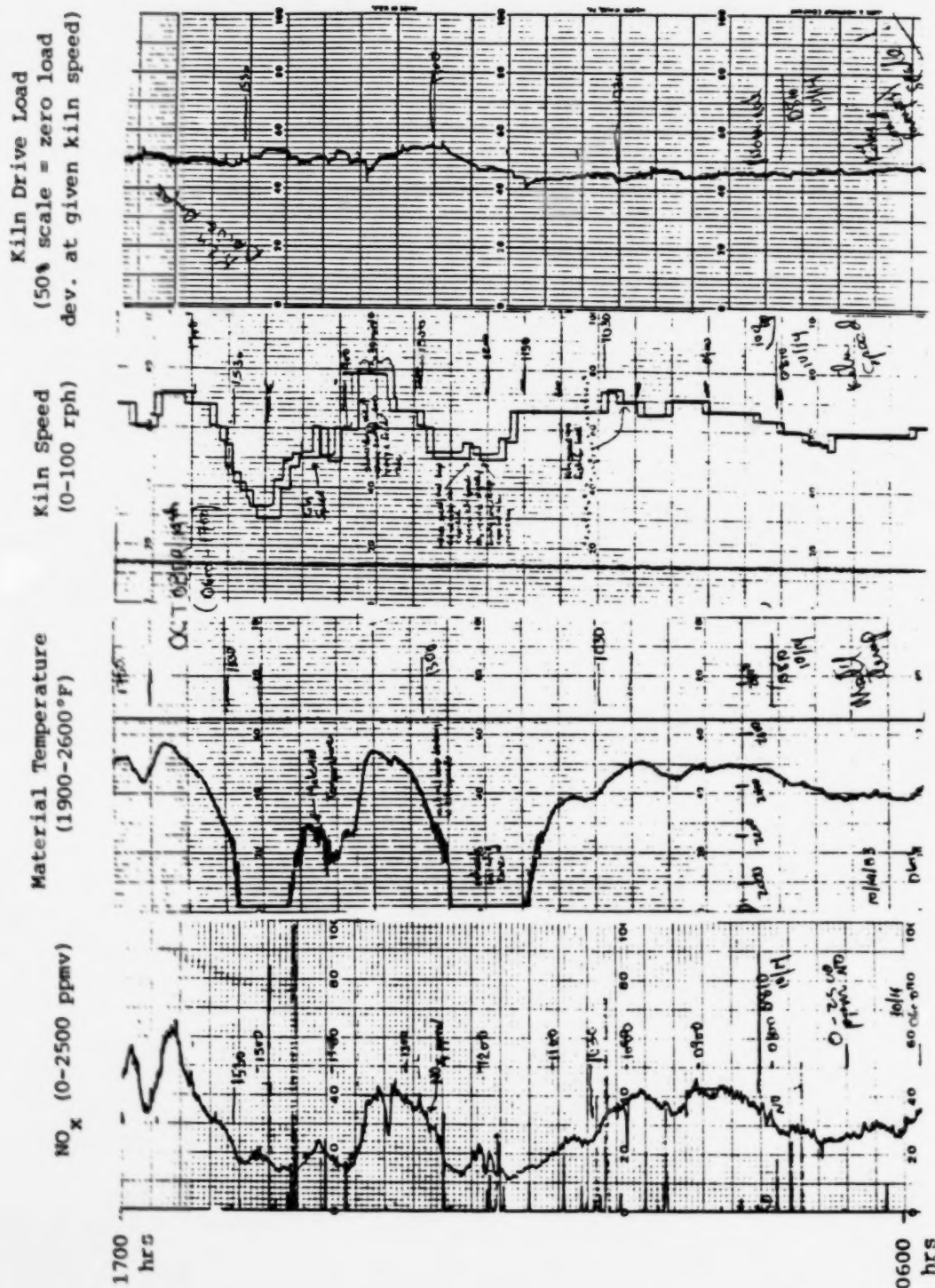


Figure E-43. Oct. 14 (NO_x, Material Temp., Kiln Speed, Kiln Drive Load); 0600-1700 hrs

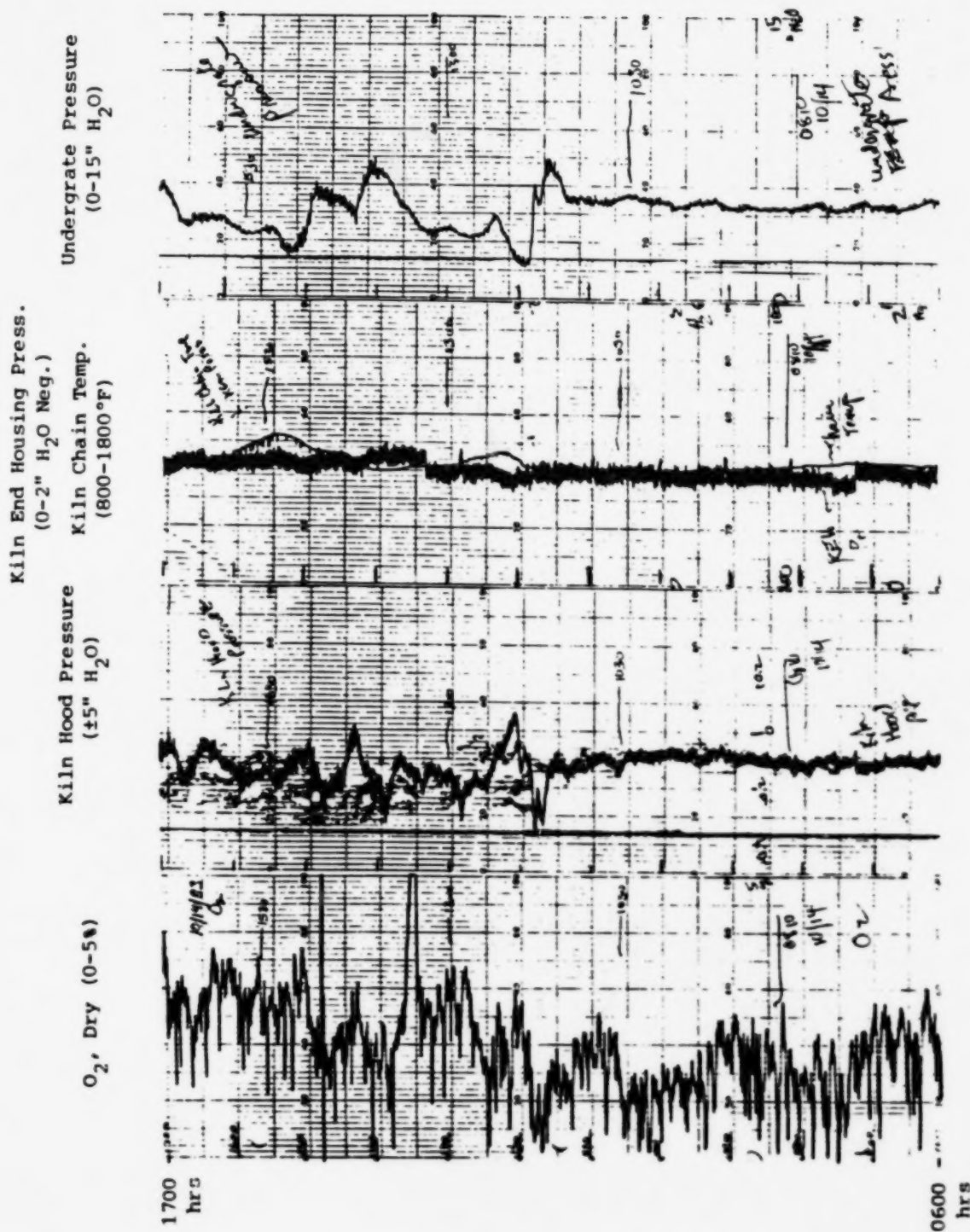


Figure E-44. (O₂, Kiln Hood Pressure, Kiln End Housing Pressure, Kiln Chain Temp., Undergrate Pressure); 0600-1700 hrs

Clinker Cooler Air
Temperature (0-2000°F)

Clinker Cooler Speed
(0-25 rpm)

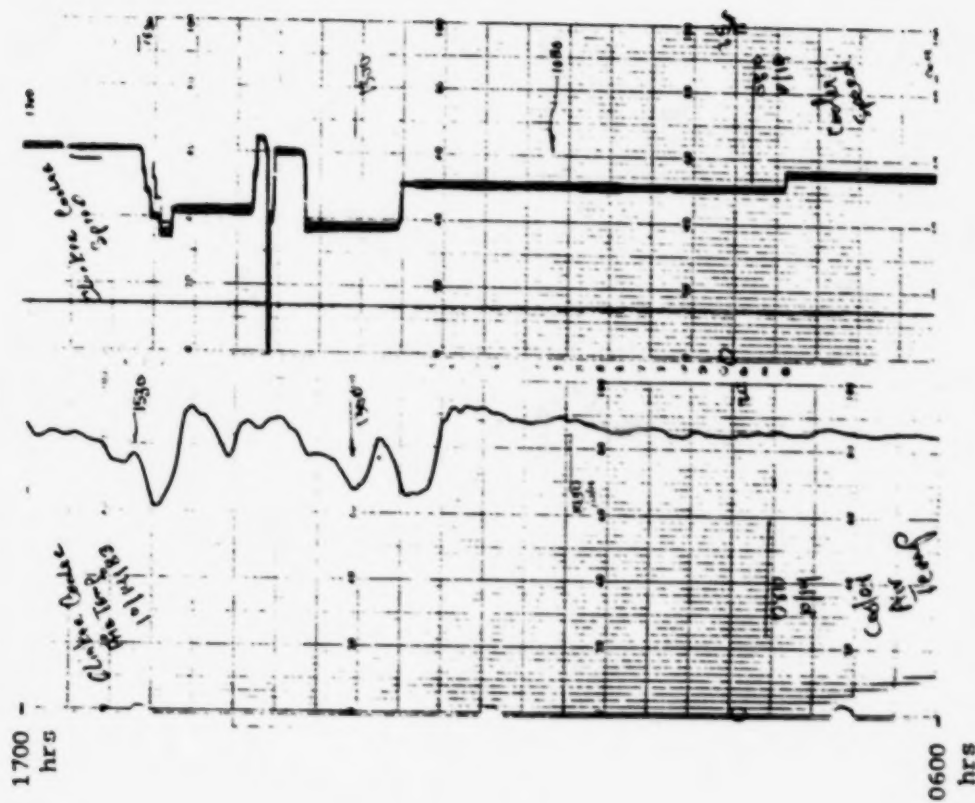


Figure E-45. Oct. 14 (Clinker Cooler Air Temp., Clinker Cooler Speed); 0600-1700 hrs

APPENDIX E-2

SAMPLE INVENTORY AND ANALYSIS

S I T E 4
EPA 806038, KILN FEED SAMPLES

SAMPLE #	DATE 1983	TIME	SAMPLE LOCATION	KILN CONDITION	ANALYZED	FEED + COAL ASH BURNABILITY FACTOR	BURNABILITY INDEX
F-0	9/27	1105	EAST SLIDE CHUTE	AS FOUND	Y	109.6	3.31
F-1	9/27	1330	EAST SLIDE CHUTE	AS FOUND	Y	107.4	3.47
F-2	9/28	1330	EAST SLIDE CHUTE	AS FOUND	Y	110.1	2.47
F-3	9/29	1105	EAST SLIDE CHUTE	AS FOUND	Y	-	-
F-4	9/29	1330	EAST SLIDE CHUTE	AS FOUND	Y	107.9	3.35
F-5	9/30	1020	EAST SLIDE CHUTE	AS FOUND	Y	104.7	2.85
F-6	9/30	1340	EAST SLIDE CHUTE	AS FOUND	Y	108.5	3.41
F-7	10/3	0900	WEST SLIDE CHUTE	AS FOUND	Y	109.5	3.41
F-8	10/3	1045	WEST SLIDE CHUTE	AS FOUND	Y	115.7	4.30
F-9	10/3	1330	WEST SLIDE CHUTE	AS FOUND	Y	112.3	3.70
F-10	10/4	0840	WEST SLIDE CHUTE	AS FOUND	Y	109.0	3.39
F-11	10/4	1045	WEST SLIDE CHUTE	AS FOUND	Y	118.5	4.88
F-12	10/4	1100	MULTICLONE	AS FOUND	Y	-	-
F-13	10/4	1245	WEST SLIDE CHUTE	AS FOUND	Y	105.4	3.07
F-14	10/5	0845	EAST SLIDE CHUTE	AS FOUND	Y	109.5	3.46
F-15	10/5	1045	EAST SLIDE CHUTE	AS FOUND	Y	109.8	3.53
F-16	10/5	1300	EAST SLIDE CHUTE	AS FOUND	Y	107.9	3.21
F-17	10/6	0845	EAST SLIDE CHUTE	AS FOUND	Y	111.2	3.70
F-18	10/7	0950	EAST SLIDE CHUTE	AS FOUND	Y	109.2	3.36
F-19	10/7	1405	EAST SLIDE CHUTE	AS FOUND	Y	111.1	3.40
F-20	10/10	0845	WEST SLIDE CHUTE	AS FOUND	Y	107.3	2.80
F-21	10/10	1045	WEST SLIDE CHUTE	AS FOUND	Y	109.5	3.14
F-22	10/10	1305	WEST SLIDE CHUTE	AS FOUND	Y	104.2	2.22
F-23	10/11	0845	WEST SLIDE CHUTE	AS FOUND	Y	106.3	2.53
F-24	10/11	0947	WEST SLIDE CHUTE	AS FOUND	Y	105.6	2.42
F-25	10/11	0948	WEST SLIDE CHUTE	AS FOUND	Y	106.8	2.67
F-26	10/11	0949	WEST SLIDE CHUTE	AS FOUND	Y	106.5	2.58
F-27	10/11	0950	WEST SLIDE CHUTE	AS FOUND	Y	106.3	2.59
F-28	10/11	0951	WEST SLIDE CHUTE	AS FOUND	Y	105.4	2.44
F-29	10/11	1300	WEST SLIDE CHUTE	AS FOUND	Y	108.0	2.79
F-30	10/12	0905	WEST SLIDE CHUTE	AS FOUND	Y	110.3	3.33
F-31	10/13	0845	WEST SLIDE CHUTE	AS FOUND	Y	110.5	3.31
F-32	10/11	1000	MULTICLONE	AS FOUND	N	-	-
F-33	10/13	0950	COMBINED	AS FOUND	Y	109.1	3.12
F-34	10/13	1025	WEST SLIDE CHUTE	AS FOUND	Y	109.2	3.17
F-35	10/13	1300	WEST SLIDE CHUTE	AS FOUND	Y	109.7	2.54
F-36	10/14	0845	WEST SLIDE CHUTE	AS FOUND	Y	110.7	3.79
F-37	10/14	0910	COMBINED	AS FOUND	Y	111.3	3.93
F-38	10/14	1135	WEST SLIDE CHUTE	AS FOUND	Y	107.0	3.28
F-39	10/14	1310	WEST SLIDE CHUTE	AS FOUND	Y	109.8	3.65
F-40	10/24	0930	EAST SLIDE CHUTE	AS FOUND	Y	119.3	4.00
F-41	10/24	1245	EAST SLIDE CHUTE	AS FOUND	Y	117.5	3.60
F-42	10/24	0935	EAST SLIDE CHUTE	AS FOUND	Y	117.8	3.79

FORMULAE FOR FEED BURNABILITY:

LINE SATURATION FACTOR =	100 CAO
(LSF)	$2.8 \text{ SiO}_2 + 1.1 \text{ Al}_2\text{O}_3 + 0.7 \text{ Fe}_2\text{O}_3$
SILICA RATIO =	SiO ₂
(SR)	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$
PERCENT FLUX =	$1.13 \text{ C}_3\text{A} + 1.35 \text{ C}_4\text{AF} + \text{MGO} + \text{ALKALIES (Na}_2\text{O} + \text{K}_2\text{O)}$
BURNABILITY INDEX =	C ₃ S
	$\text{C}_4\text{AF} + \text{C}_3\text{A}$
BURNABILITY FACTOR =	$(\text{LSF}) + 10(\text{SR}) - 3(\text{MGO} + \text{ALKALIES})$

S I T E 4
EPA 806030. CLINKER SAMPLES

SAMPLE #	DATE 1983	TIME	SAMPLE LOCATION	KILN CONDITION	HOST SITE	ANALYSIS FREE LINE KVP					COMMENTS
						1	2	3	4	5	
C-1	9/26	1535	KILN OUTLET	AS FOUND	0.14	0.06	-	-	-	-	
C-2	9/27	1100	KILN OUTLET	AS FOUND	0.23	0.08	-	-	-	-	
C-3	9/27	1300	KILN OUTLET	AS FOUND	0.16	0.05	-	-	-	-	
C-4	9/27	1520	KILN OUTLET	AS FOUND	0.65	0.60	0.61	0.62	-	-	
C-5	9/28	1000	KILN OUTLET	AS FOUND	0.22	0.12	0.14	-	-	-	
C-5A	9/28	1100	KILN OUTLET	AS FOUND	0.28	0.21	-	-	-	-	
C-6	9/28	1130	WEIGH BELT	AS FOUND	0.19	0.12	-	-	-	-	
C-7	9/28	1200	KILN OUTLET	AS FOUND	0.16	0.14	-	-	-	-	
C-8	9/28	1300	KILN OUTLET	AS FOUND	0.17	0.07	0.14	-	-	-	
C-9	9/28	1400	KILN OUTLET	AS FOUND	0.17	0.08	0.08	-	-	-	
C-10	9/28	1520	KILN OUTLET	AS FOUND	0.22	0.03	0.03	0.08	0.08	-	
C-11	9/29	1100	KILN OUTLET	AS FOUND	0.18	0.09	0.09	-	-	-	
C-12	9/29	1220	KILN OUTLET	AS FOUND	0.71	0.54	0.56	0.58	-	-	
C-13	9/29	1400	KILN OUTLET	AS FOUND	0.27	0.19	-	-	-	-	
C-14	9/29	1500	KILN OUTLET	AS FOUND	4.87	3.85	3.85	4.00	-	-	
C-15	9/30	1010	WEIGH BELT	AS FOUND	0.12	0.08	0.08	-	-	-	
C-16	9/30	1115	WEIGH BELT	AS FOUND	0.26	0.09	0.09	-	-	-	
C-17	9/30	1215	WEIGH BELT	AS FOUND	0.18	0.13	-	-	-	-	
C-18	9/30	1320	WEIGH BELT	AS FOUND	0.22	0.16	0.15	-	-	-	
C-19	9/30	1500	WEIGH BELT	AS FOUND	0.39	0.29	-	-	-	-	
C-20	10/3	1010	WEIGH BELT	AS FOUND	0.22	0.19	0.19	-	-	-	
C-21	10/3	1100	WEIGH BELT	AS FOUND	0.41	0.30	0.25	-	-	-	
C-22	10/3	1200	KILN OUTLET	AS FOUND	0.50	0.26	0.24	-	-	-	
C-23	10/3	1320	WEIGH BELT	AS FOUND	0.58	0.42	-	-	-	-	
C-25	10/3	1410	WEIGH BELT	AS FOUND	0.40	0.20	0.20	0.19	-	-	
C-26	10/3	1545	WEIGH BELT	AS FOUND	0.31	0.20	0.22	0.21	-	-	
C-27	10/4	0900	KILN OUTLET	AS FOUND	0.26	0.12	0.14	-	-	-	
C-28	10/4	1020	KILN OUTLET	AS FOUND	0.56	0.39	0.42	-	-	-	
C-29	10/4	1120	KILN OUTLET	AS FOUND	3.60	3.06	3.04	-	-	-	
C-30	10/4	1300	KILN OUTLET	AS FOUND	0.20	0.15	0.14	-	-	-	
C-31	10/5	1000	KILN OUTLET	AS FOUND	0.15	0.08	0.09	-	-	-	
C-32	10/5	1100	KILN OUTLET	AS FOUND	0.17	0.05	0.05	-	-	-	
C-33	10/5	1200	KILN OUTLET	AS FOUND	0.22	0.15	0.14	-	-	-	
C-34	10/5	1300	KILN OUTLET	AS FOUND	0.10	0.05	0.07	0.07	-	-	
C-35	10/5	1400	KILN OUTLET	AS FOUND	0.24	0.03	0.03	0.11	-	-	
C-38	10/6	1010	KILN OUTLET	AS FOUND	0.29	0.08	0.09	0.08	-	-	
C-38A	10/6	1120	KILN OUTLET	AS FOUND	0.23	0.18	0.16	-	-	-	
C-39	10/7	1425	KILN OUTLET	AS FOUND	0.20	0.14	0.16	-	-	-	
C-40	10/10	1100	KILN OUTLET	AS FOUND	0.50	0.38	0.35	-	-	-	
C-41	10/10	1200	KILN OUTLET	AS FOUND	0.12	0.08	0.08	-	-	-	
C-42	10/10	1300	KILN OUTLET	AS FOUND	0.24	0.08	-	-	-	-	
C-43	10/10	1400	KILN OUTLET	AS FOUND	0.14	0.09	0.09	-	-	-	
C-44	10/10	1500	KILN OUTLET	AS FOUND	0.12	0.07	-	-	-	-	
C-45	10/11	1100	WEIGH BELT	AS FOUND	0.34	0.16	0.14	0.18	-	-	
C-46	10/11	1202	WEIGH BELT	AS FOUND	0.24	0.05	0.07	-	-	-	
C-47	10/11	1203	WEIGH BELT	AS FOUND	0.15	0.04	0.04	-	-	-	
C-48	10/11	1204	WEIGH BELT	AS FOUND	0.21	0.03	0.04	0.08	-	-	
C-49	10/11	1205	WEIGH BELT	AS FOUND	0.20	0.04	0.05	-	-	-	
C-50	10/11	1206	WEIGH BELT	AS FOUND	0.16	0.05	0.07	-	-	-	
C-51	10/11	1430	WEIGH BELT	AS FOUND	0.21	0.12	0.12	-	-	-	
C-52	10/11	1530	WEIGH BELT	AS FOUND	0.14	0.07	0.06	-	-	-	
C-53	10/12	1020	WEIGH BELT	AS FOUND	0.29	0.15	0.14	-	-	-	
C-54	10/13	1025	WEIGH BELT	AS FOUND	0.36	0.25	0.24	-	-	-	
C-55	10/13	1115	WEIGH BELT	AS FOUND	0.45	0.31	0.28	-	-	-	
C-56	10/13	1315	WEIGH BELT	AS FOUND	0.13	0.04	0.04	-	-	-	
C-57	10/13	1510	WEIGH BELT	AS FOUND	0.36	0.28	0.27	-	-	-	
C-58	10/14	1015	KILN OUTLET	AS FOUND	-	0.12	0.14	-	-	-	
C-59	10/14	1325	KILN OUTLET	AS FOUND	-	0.04	0.05	0.05	0.07	-	
C-60	10/24	1100	KILN OUTLET	AS FOUND	2.32	1.70	1.38	1.34	-	-	
C-61	10/24	1200	KILN OUTLET	AS FOUND	0.52	0.28	0.27	-	-	-	
C-62	10/24	1300	KILN OUTLET	AS FOUND	8.81	5.73	5.69	-	-	-	
C-63	10/24	1410	KILN OUTLET	AS FOUND	2.23	1.79	1.78	-	-	-	
C-64	10/24	1415	KILN OUTLET	AS FOUND	1.48	1.03	1.03	-	-	-	
C-65	10/24	1420	KILN OUTLET	AS FOUND	1.07	0.73	0.73	-	-	-	
C-66	10/24	1425	KILN OUTLET	AS FOUND	0.71	0.28	0.28	0.33	-	-	
C-67	10/24	1430	KILN OUTLET	AS FOUND	0.67	0.41	0.42	-	-	-	
C-68	10/24	1435	KILN OUTLET	AS FOUND	0.43	0.35	0.37	-	-	-	

KILN UPSET DURING AM

S I T E 4
EPA 806038. COAL SAMPLES

SAMPLE #	DATE 1983	TIME	SAMPLE LOCATION	KILN CONDITION	ANALYZED	COMMENTS
-----	----	----	-----	-----	-----	-----
COAL-1	9/30	0900	BURNER PIPE	AS FOUND	N	
COAL-2	9/30	1550	BURNER PIPE	AS FOUND	Y	
COAL-3	10/3	1400	BURNER PIPE	AS FOUND	Y	
COAL-4	10/4	1055	BURNER PIPE	AS FOUND	N	
COAL-5	10/5	0915	BURNER PIPE	AS FOUND	Y	
COAL-6	10/10	1100	BURNER PIPE	AS FOUND	Y	
COAL-7	10/11	1000	BURNER PIPE	AS FOUND	Y	
COAL-8	10/11	1430	BURNER PIPE	AS FOUND	Y	
COAL-9	10/12	1000	BURNER PIPE	AS FOUND	N	
COAL-10	10/13	0920	BURNER PIPE	AS FOUND	N	
COAL-11	10/14	0945	BURNER PIPE	AS FOUND	N	
COAL-12	10/14	1350	BURNER PIPE	AS FOUND	Y	
COAL-13	10/24	1110	BURNER PIPE	AS FOUND	N	

EPA. 806030. COAL SAMPLES ANALYSES

[illegible]

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES 286 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-8434

DIVISION MANAGER
LMER



PLEASE ADDRESS ALL CORRESPONDENCE TO
1489 CANAL AVE., LONG BEACH, CA 90813
OFFICE TEL (213) 437-6668

TO
006 Skypark Blvd.
O. Box 19518
Irvine, Ca. 92714

December 19, 1983

Sample identification
by

Commercial Testing & Engineering

Sample
to us

Coal

10/14/83 1350

Sample # 12

on at

XXXX

by

KVB

dated

10/14/83

received

10/18/83

Analysis report no. 77-1705 Page 2

PARTICLE SIZE DISTRIBUTION

MICRON SIZE SCREEN ANALYSIS	Above Stated Micron (By Weight)
420	0.00
210	0.00
105	2.96
75	7.77
45	30.69

COULTER COUNTER

40.30	31.80
32.00	33.47
25.40	39.16
20.20	44.71
16.00	52.35
12.70	61.49
10.08	70.87
8.00	79.67
6.35	87.07
5.04	92.57

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

Dennis Shaw

Manager, Long Beach Laboratory



OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS,
TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

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 South Holland, IL 60473
 16130 Van-Drun Road,
 (312) 264-1173

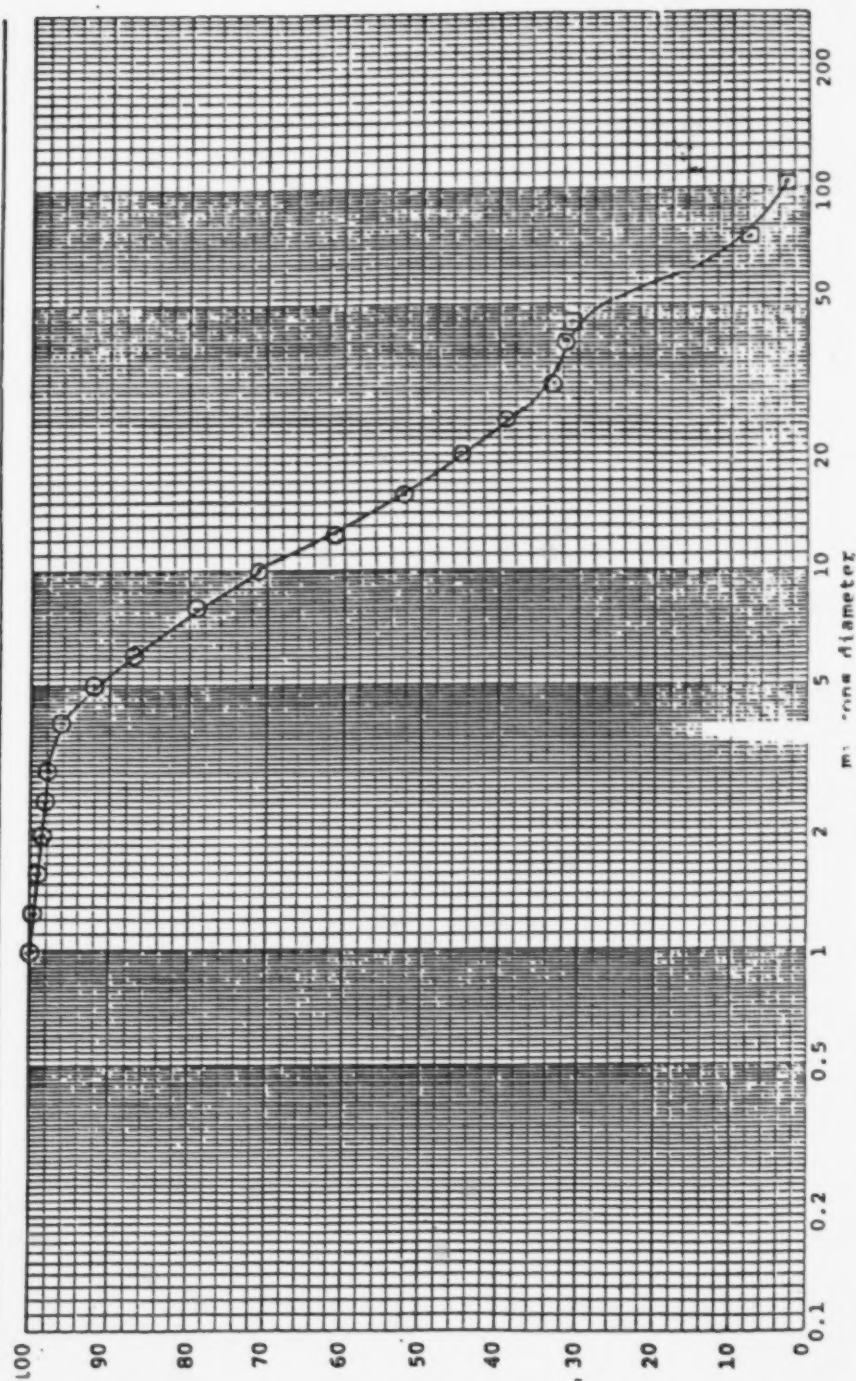
PARTICLE SIZE ANALYSIS

COULTER COUNTER*

Source 79-10515 (1705)

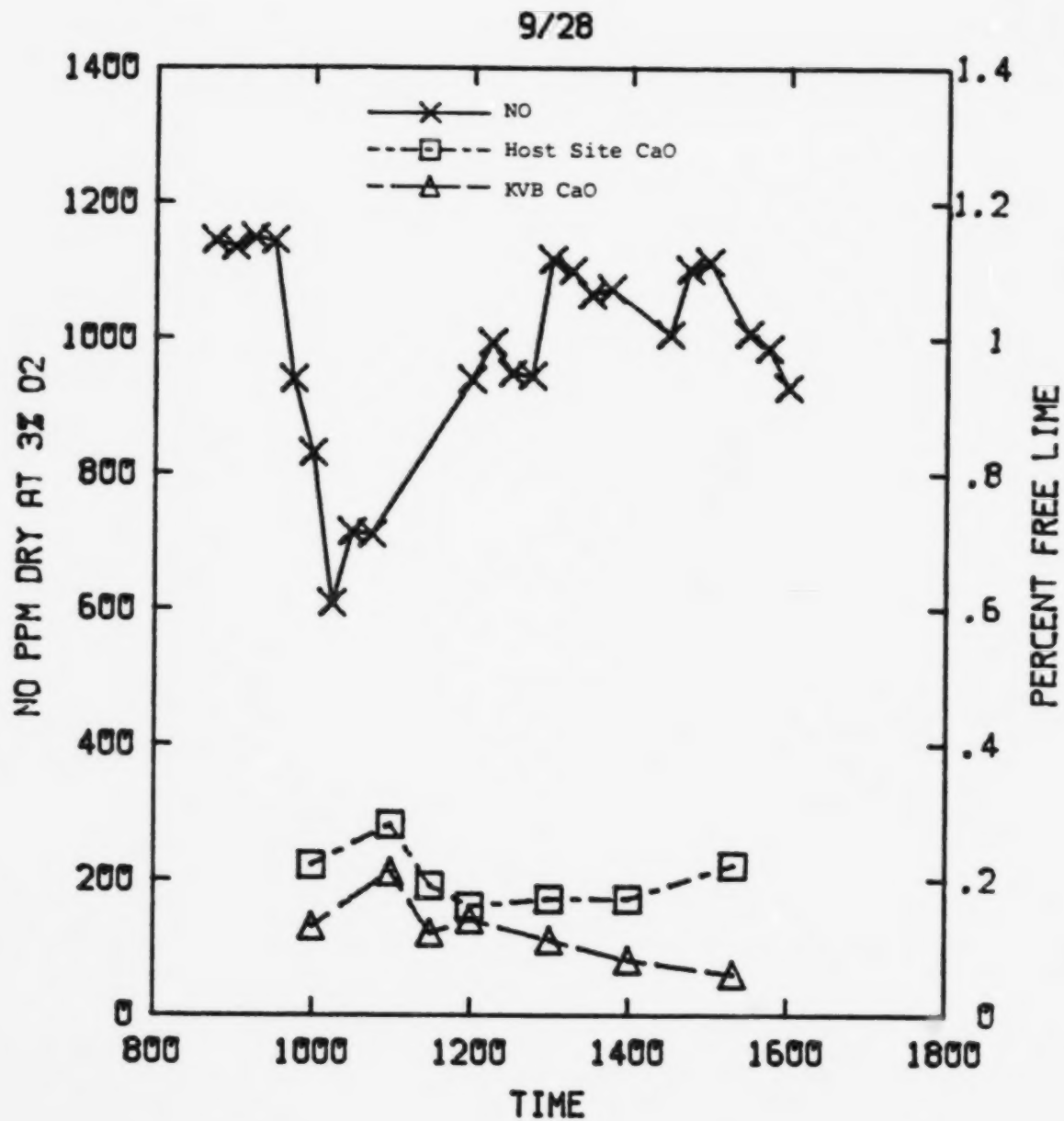
Operator RS Date

Material and sample no.		electrolyte & dispersant aperture	
☒ Coulter Counter Analysis	Isoton	100u	Sample was passed thru 420,210,105,45
☒ Screen Analysis	Aerosol OT	30u	micron sieves and particles below 45
☒ A	Ultrasonic bath		micron was analyzed by Coulter Counter
☒ ϕ			

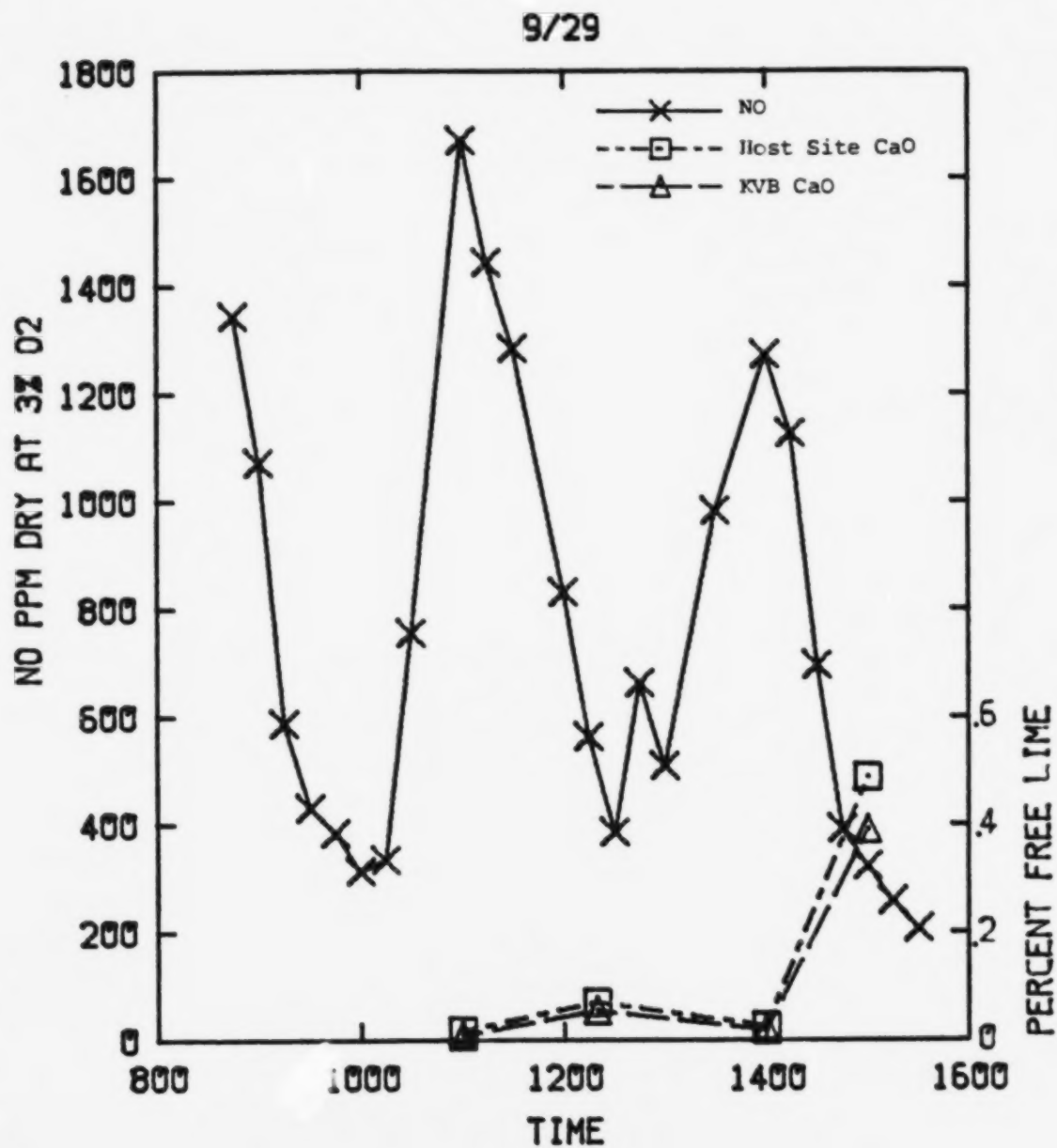


APPENDIX E-3

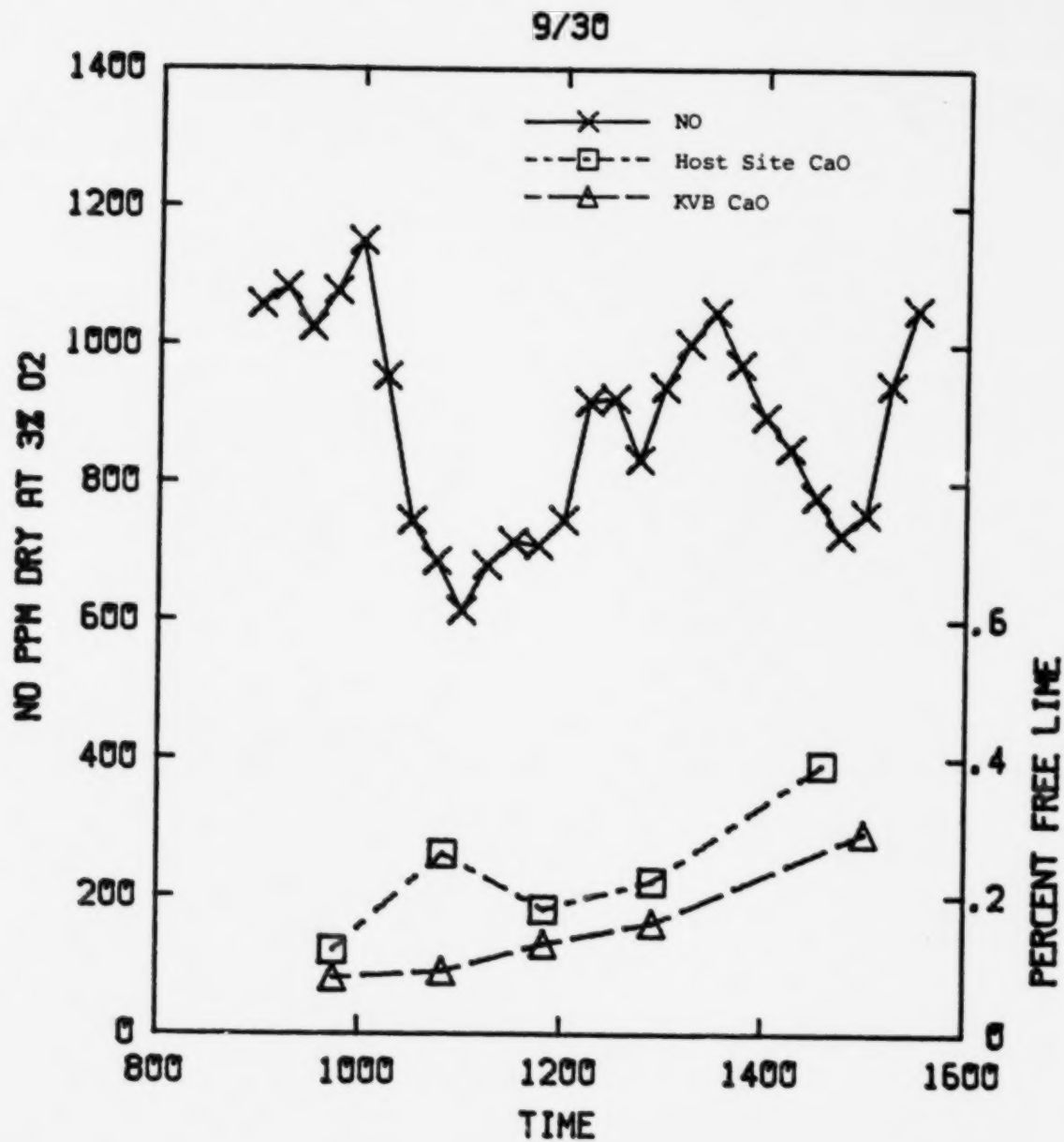
AS-FOUND NO EMISSIONS DATA VERSUS FREE LIME



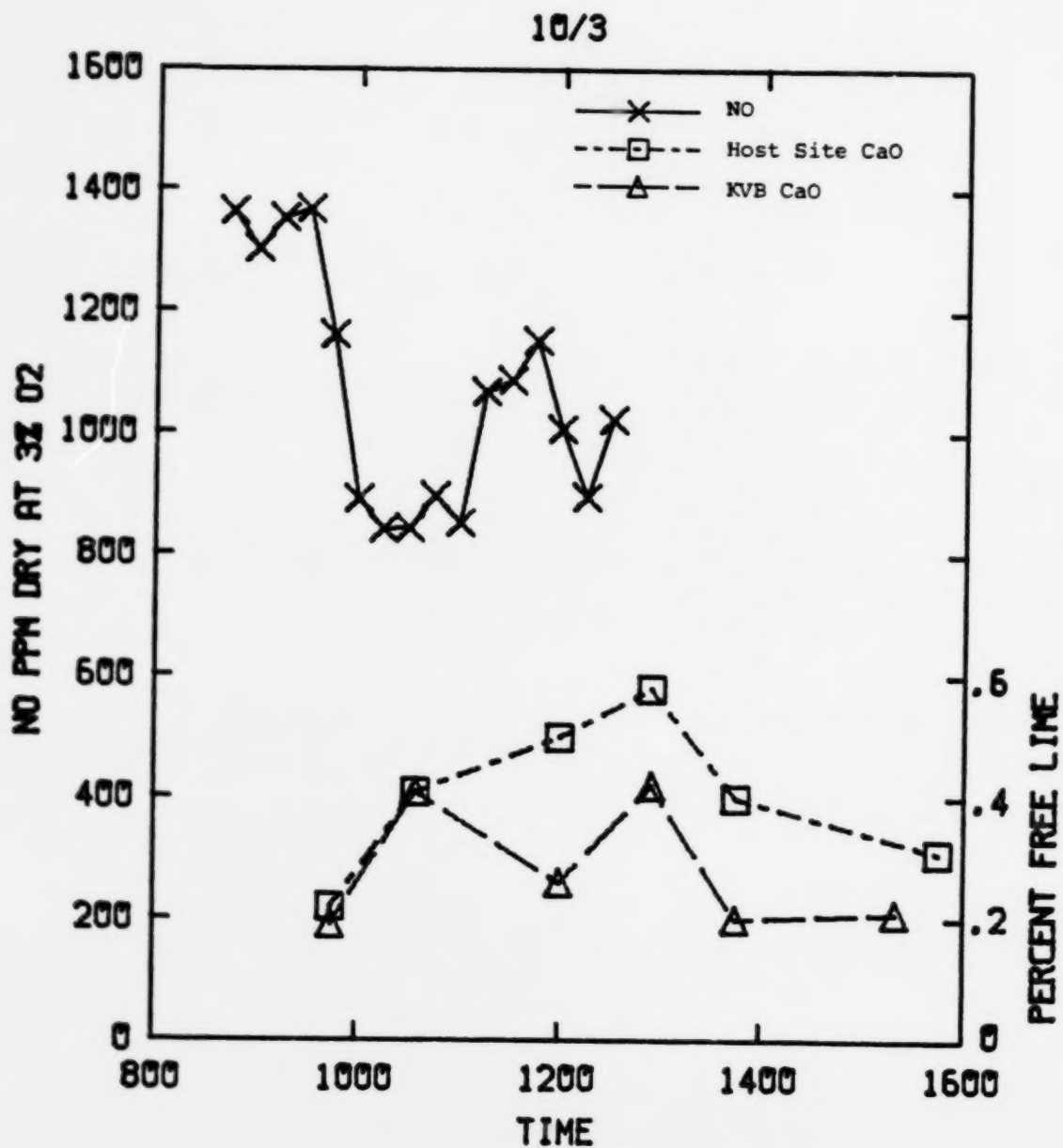
9/28 - Time Trace of NO and Free Lime



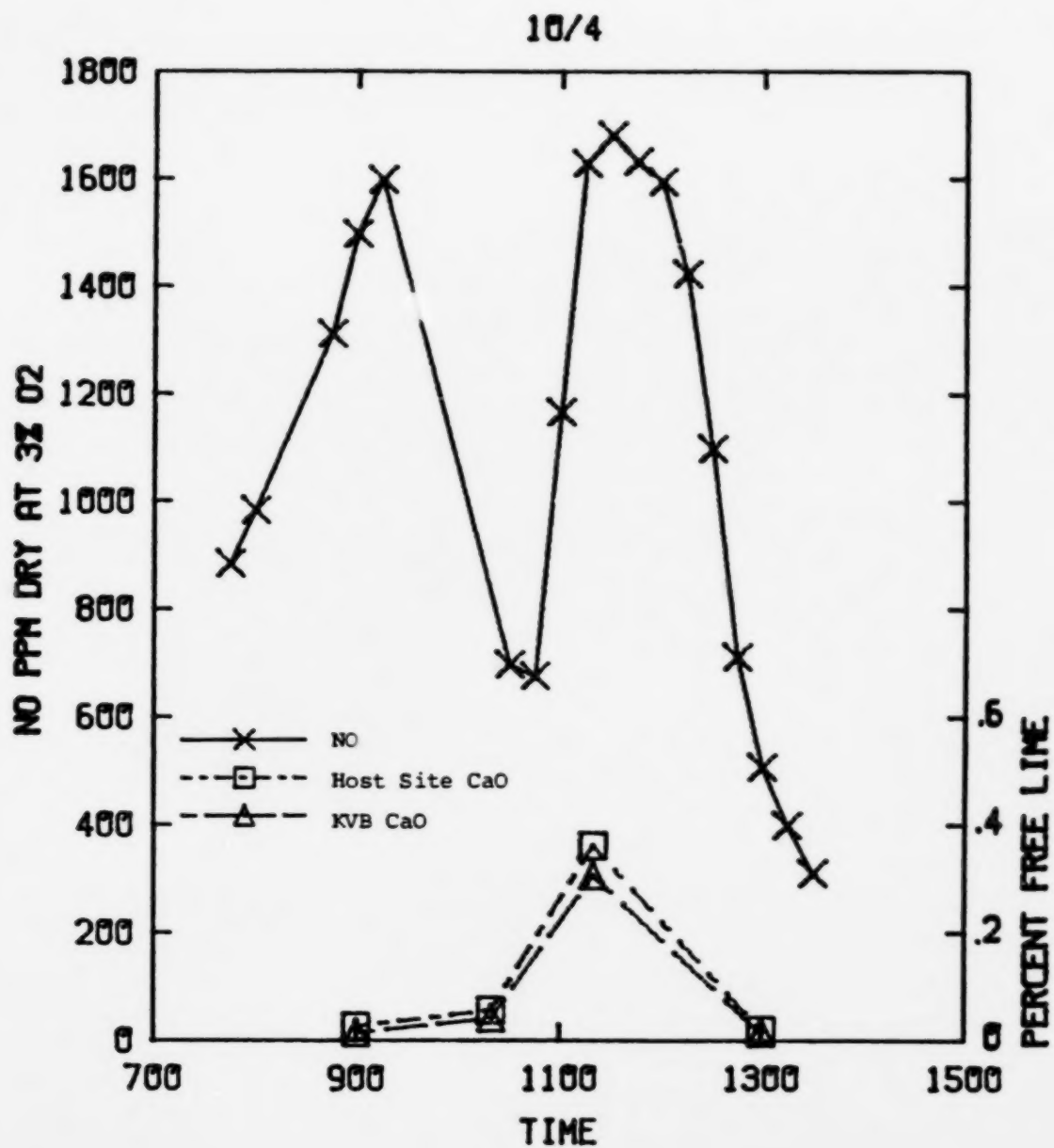
9/29 - Time Trace of NO and Free Lime



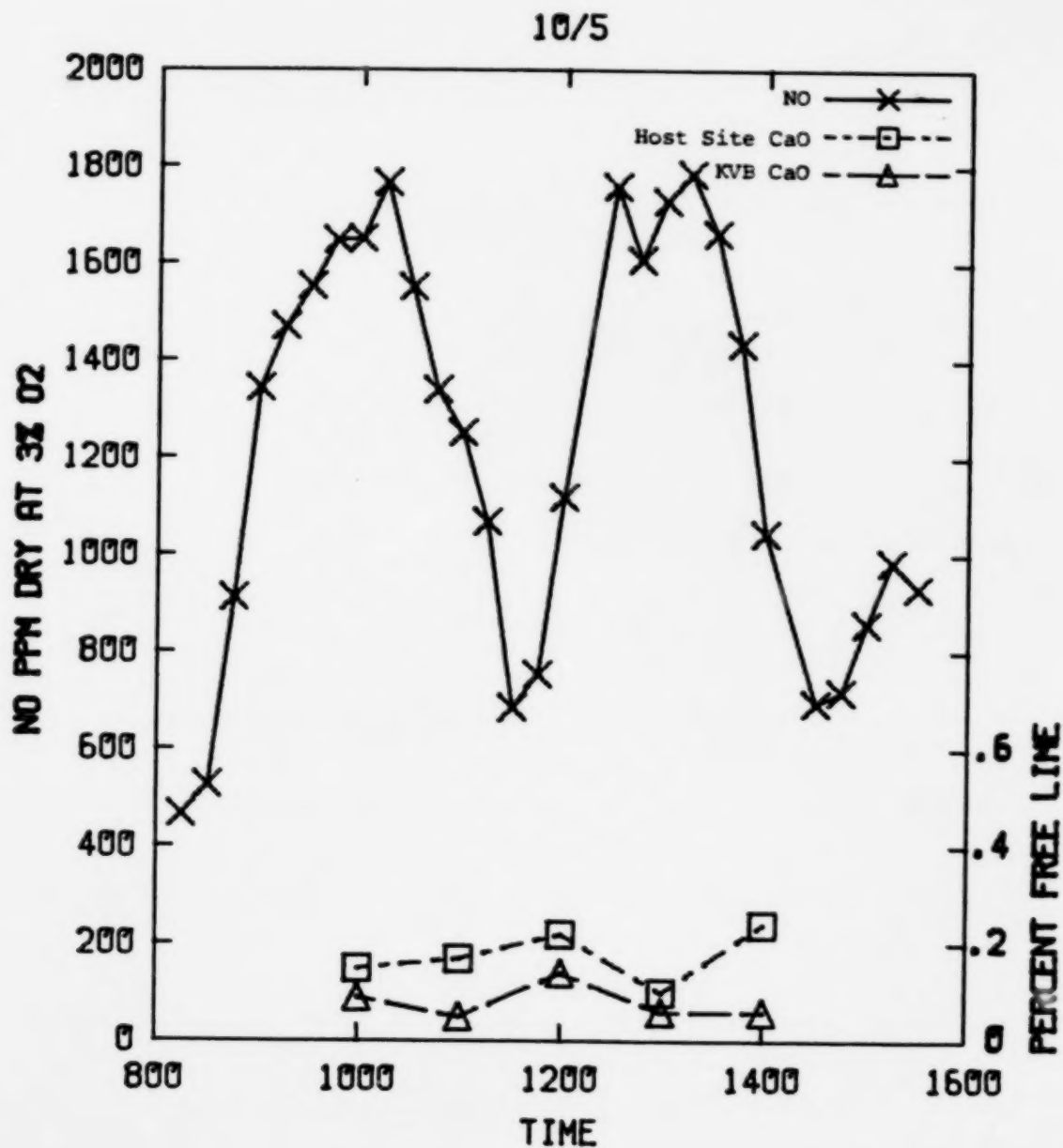
9/30 - Time Trace of NO and Free Lime



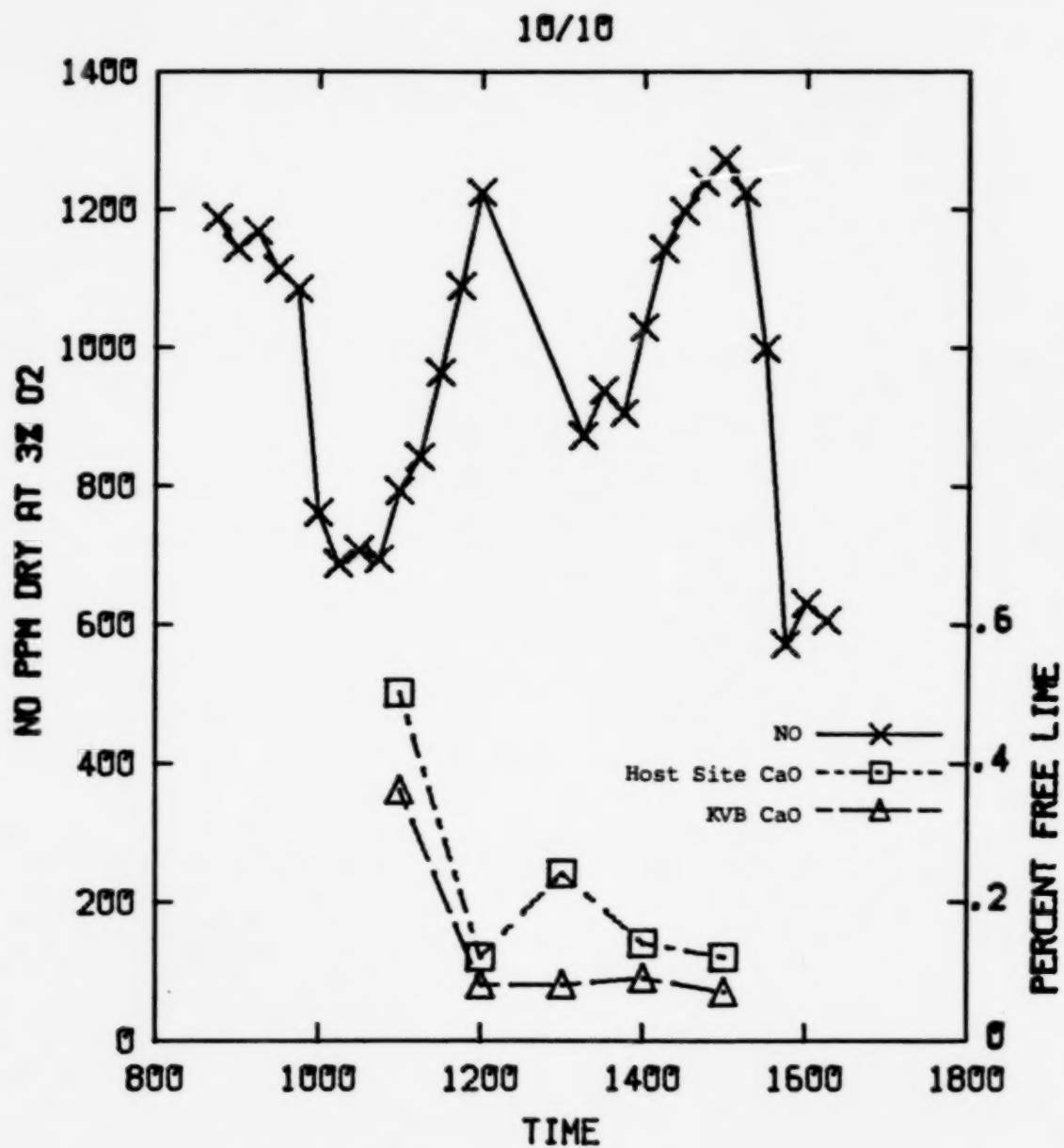
10/3 - Time Trace of NO and Free Lime



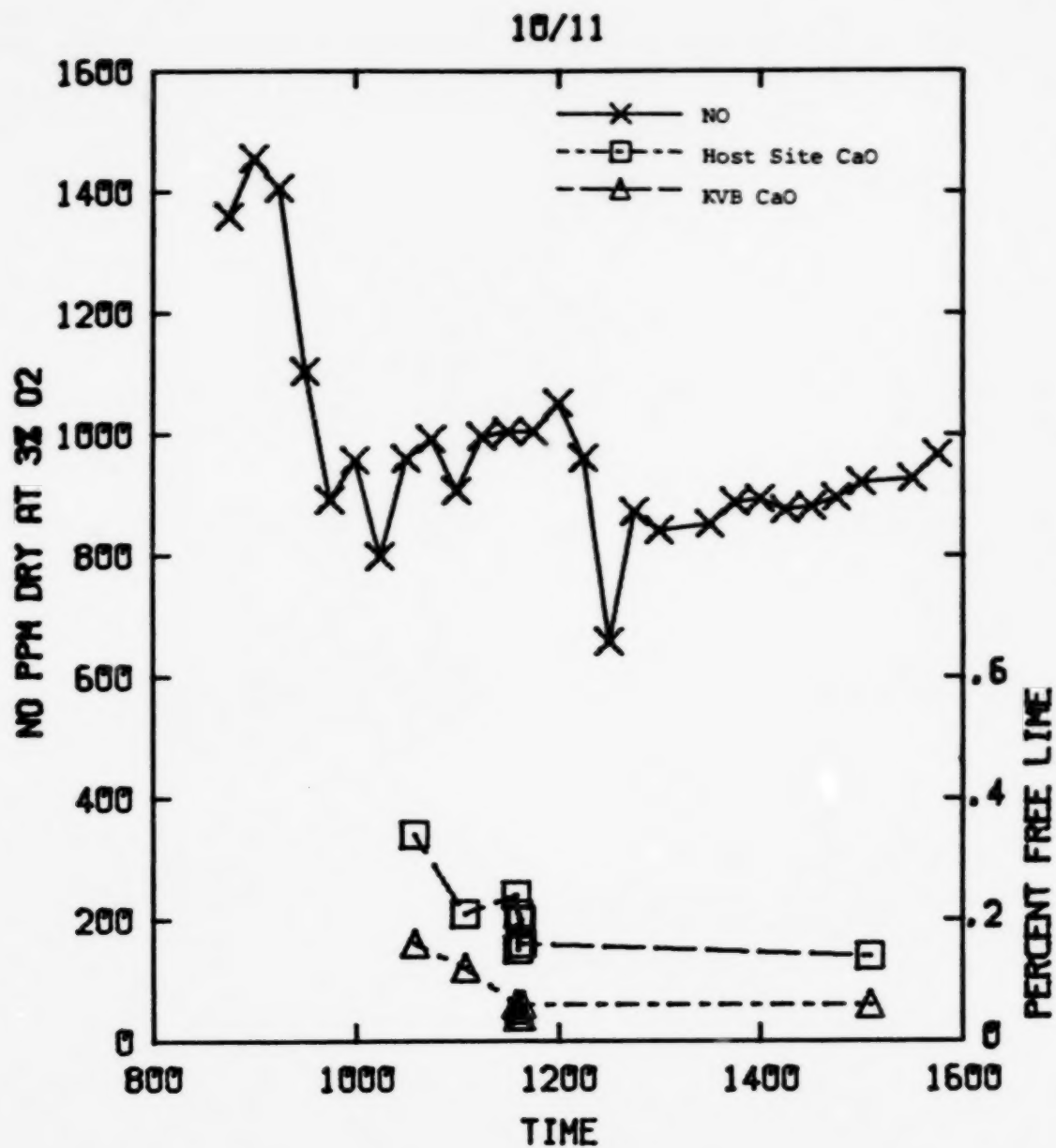
10/4 - Time Trace of NO and Free Lime



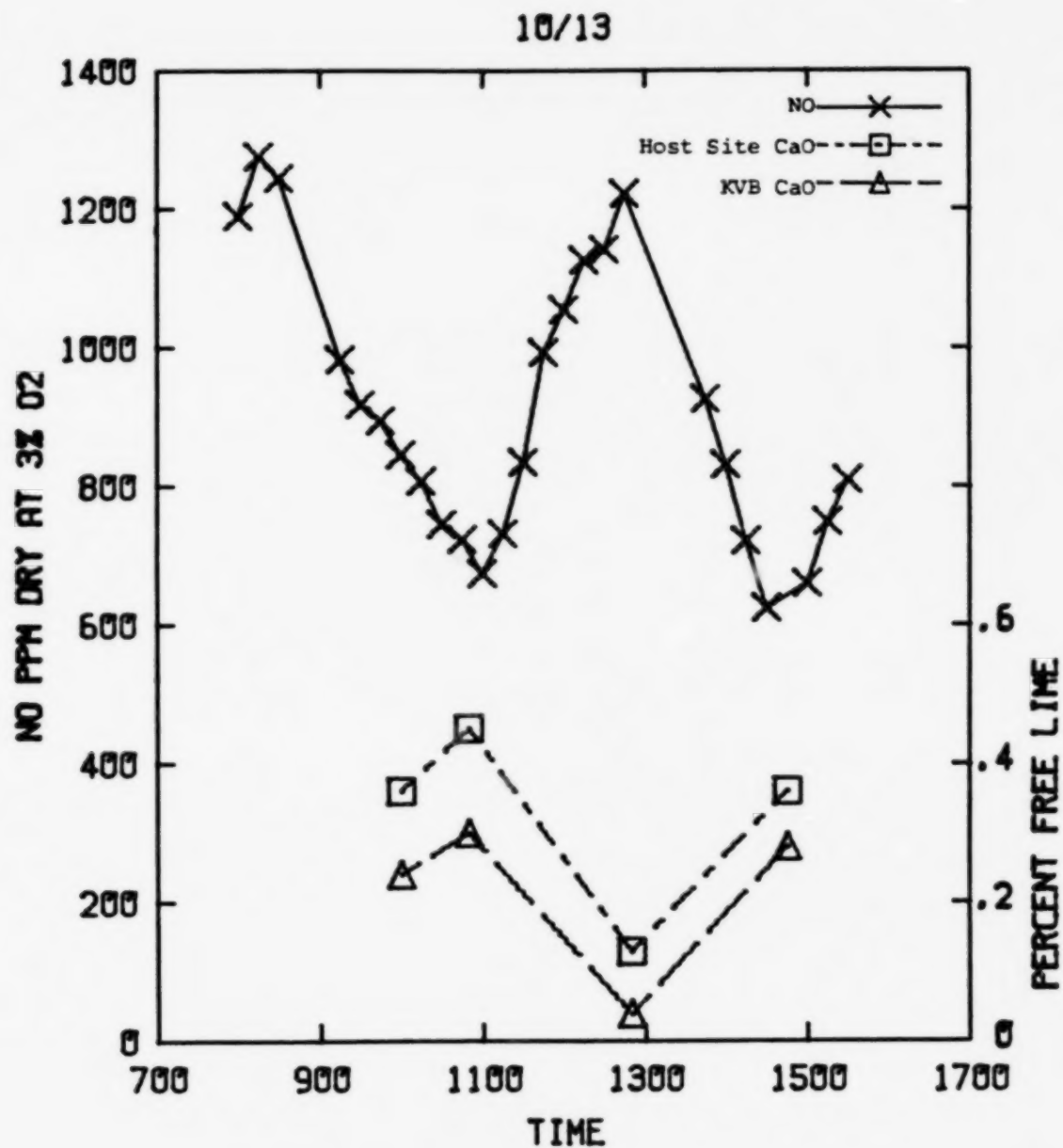
10/5 - Time Trace of NO and Free Lime



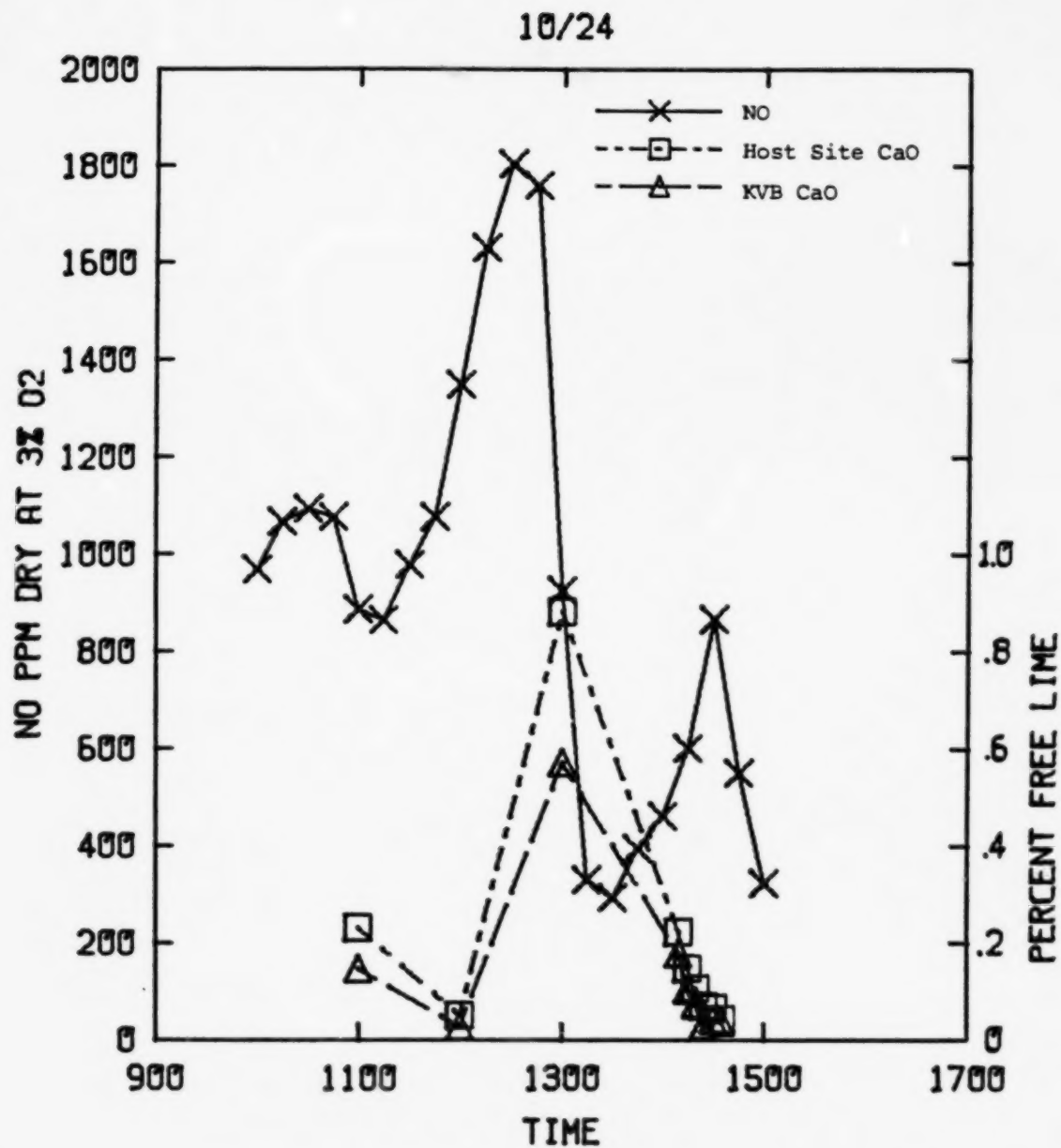
10/10 - Time Trace of NO and Free Lime



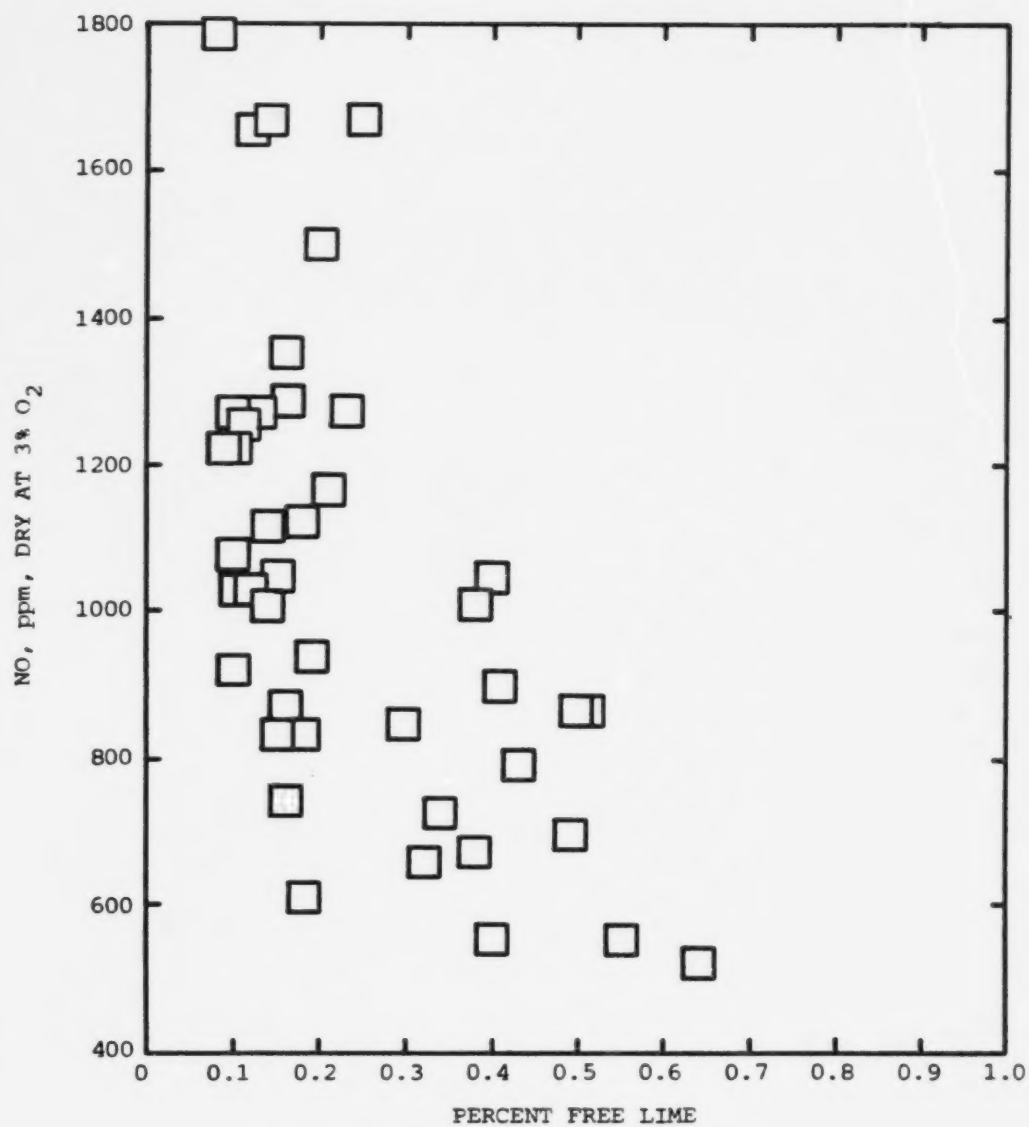
10/11 - Time Trace of NO and Free Lime



10/13 - Time Trace of NO and Free Lime



10/24 - Time Trace of NO and Free Lime



NO versus Free Lime

APPENDIX E-4

EMISSIONS DATA

SITE 4 ROTARY KILN

DATE - 9-26-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 9.13**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1130	2.3	26.7	--	1527	--	1031	6.74	16.16
1145	1.1	29	--	1155	--	787	6.34	11.6
1200	1.4	26.1	--	1207	--	792	8.45	15.56
1300	2.2	26.9	--	1852	--	1252	6.69	19.49
1315	2	29.6	--	1619	--	1138	5.22	13.8
1330	2.4	31.5	--	1533	--	1125	4.15	10.86
1345	2.1	32.1	--	1184	--	870	4.12	8.34
1400	2.3	30.1	--	1499	--	1071	4.76	11.86
1415	2.1	29.4	--	1818	--	1277	5.24	15.55
1430	1.7	29.9	--	1762	--	1235	5.3	15.22
1445	2.1	29.8	--	1529	--	1081	5.04	12.68
1500	2.4	29.4	--	1450	--	1026	5.01	11.95
1615	3	32.5	--	1553	--	1183	3.51	9.66
1630	2.6	32.9	--	1456	--	1103	3.6	9.23

STATISTICAL DATA

MEAN	2.1	29.7	0	1510	0	1069	5.3	13
STD DEV	.48	2.11	0	218.56	0	158.27	1.37	3.12
CI95 MN	.28	1.22	0	126.17	0	91.37	.79	1.8
(N)	14	14	0	14	0	14	14	14

*METHOD 1 CLINKER RATE (TONS/HR) - 42

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.89
(TIME WEIGHTED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 47

EMISSION FACTORS

MMBTU / TON CLINKER = 4.76
LBS DRY FEED / MMBTU = 720
CO2 SCF / MMBTU = 2218
TOT SCF / MMBTU = 11917
NO LBS / SCF (3% O2) = 1.8 E-04
NO LBS / MMBTU = 2.51
NO LBS / TON CLINKER = 11.95

NO ON A MASS BASIS IN TERMS OF NO2 -

- * METHOD 1 : KVB GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE
- * METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)
- ** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 9-27-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 9.17**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
915	2.1	28.8	--	1077	--	749	5.55	9.67
930	1.8	30.1	--	893	--	630	5.13	7.5
945	2.4	29.6	--	1138	--	808	4.91	9.24
1000	2.2	28.3	--	1377	--	952	5.75	12.74
1015	2.5	27.4	--	1610	--	1105	6.03	15.5
1045	2.3	28.8	--	1438	--	1005	5.39	12.59
1300	2.2	27.8	--	1253	--	859	6.06	12.12
1315	2.2	29.1	--	1029	--	717	5.47	9.13
1330	2.3	30.2	--	1072	--	767	4.72	8.42
1445	2	28.2	--	1275	--	876	6	12.22
1500	1.5	28.4	--	1020	--	695	6.35	10.26
1515	1.4	28.6	--	696	--	475	6.31	6.96
1530	1.6	29.2	--	692	--	478	5.76	6.41
1545	1.4	26.2	--	922	--	606	8.34	11.75
1600	1.8	30.4	--	1417	--	1004	4.99	11.64

STATISTICAL DATA

MEAN	2	28.7	0	1127	0	782	5.78	10.41
STD DEV	.37	1.12	0	268.97	0	189.27	.87	2.53
C195 MN	.2	.62	0	148.97	0	104.83	.48	1.4
(N)	15	15	0	15	0	15	15	15

*METHOD 1 CLINKER RATE (TONS/HR) - 39

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 14.94	MMBTU / TON CLINKER = 4.26
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 805
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2478
CLINKER RATE (TON/HR) - 52.74	TOT SCF / MMBTU = 12177
	NO LBS / SCF (3% O2) = 1.35 E-04
	NO LBS / MMBTU = 1.91
	NO LBS / TON CLINKER = 8.16

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVB CASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVB CASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 9-28-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 9.17**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
845	2.1	26.1	--	1140	--	759	7.48	13.22
900	1.9	30.4	--	1131	--	803	4.91	9.18
915	2.1	28.6	--	1144	--	793	5.67	10.45
930	2.1	28	--	1140	--	783	6.03	10.97
945	2.1	28	--	936	--	643	6.03	9.01
1000	2.1	29.3	--	827	--	580	5.29	7.13
1015	2.1	29.3	--	606	--	425	5.29	5.23
1030	2.1	28.8	--	711	--	494	5.55	6.39
1045	2	29.4	--	707	--	495	5.32	6.12
1200	1.9	29.1	--	934	--	649	5.56	8.39
1215	1.7	29.3	--	989	--	687	5.62	8.97
1230	1.5	28.5	--	944	--	644	6.28	9.41
1245	1.3	29.2	--	940	--	645	6.02	9.04
1300	1.4	27.2	--	1112	--	742	7.37	12.72
1315	1.5	29	--	1095	--	753	5.96	10.44
1330	1.5	30.2	--	1061	--	744	5.31	9.17
1345	1.5	27.6	--	1069	--	719	6.93	11.59
1430	1.3	29.1	--	1002	--	687	6.09	9.72
1445	1.5	29.7	--	1098	--	763	5.56	9.88
1500	1.5	28.6	--	1109	--	758	6.21	10.95
1530	1.6	28.6	--	1005	--	688	6.12	9.8
1545	1.4	30.1	--	982	--	685	5.43	8.66
1600	1.8	28.5	--	925	--	636	6	8.86

STATISTICAL DATA

MEAN	1.7	28.8	0	983	0	677	5.91	9.36
STD DEV	.3	.99	0	150.41	0	100.71	.65	1.94
C195 MN	.13	.43	0	65.05	0	43.55	.28	.84
(N)	23	23	0	23	0	23	23	23

*METHOD 1 CLINKER RATE (TONS/HR) - 38

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 15.27	MMBTU / TON CLINKER = 4.17
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 822
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2532
CLINKER RATE (TON/HR) - 53.89	TOT SCF / MMBTU = 12231
	NO LBS / SCF (3% O2) = 1.17 E-04
	NO LBS / MMBTU = 1.68
	NO LBS / TON CLINKER = 7

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD CASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD CASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 9-29-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.88**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV %O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
845	1.4	27.6	--	1341	--	900	7.04	14.74
900	1.3	26.8	--	1069	--	708	7.86	12.94
915	1.4	28.5	--	586	--	399	6.38	5.92
930	1.3	28.8	--	430	--	293	6.28	4.28
945	.9	29	--	384	--	260	6.53	3.96
1000	1.2	29.1	--	313	--	214	6.18	3.08
1015	1.2	28.8	--	335	--	228	6.37	3.38
1030	1.8	28	--	754	--	514	6.32	7.55
1100	3.6	25.4	--	1666	--	1206	4.44	12.46
1115	6.4	28.4	--	1440	--	1153	2.89	7.75
1130	4.9	28.3	--	1281	--	961	3.76	8.39
1200	3.2	27.7	--	829	--	582	5.23	7.08
1215	1.6	27.7	--	563	--	380	6.74	5.96
1230	1.1	29.1	--	386	--	263	6.27	3.84
1245	1.6	28.2	--	661	--	450	6.38	6.68
1300	1.6	27.3	--	509	--	342	7.05	5.6
1330	1.7	29.1	--	980	--	679	5.73	9.03
1400	1.9	29.4	--	1269	--	887	5.4	11.13
1415	2.3	29	--	1124	--	789	5.28	9.68
1430	1.6	30.2	--	694	--	488	5.23	5.93
1445	1.7	30.2	--	391	--	275	5.15	3.3
1500	1.8	30.3	--	323	--	228	5.03	2.67
1515	1.2	30.3	--	258	--	180	5.49	2.3
1530	1.2	28.3	--	207	--	140	6.72	2.19

STATISTICAL DATA

MEAN	2.1	28.6	0	741	0	522	5.82	6.66
STD DEV	1.46	1.16	0	428.64	0	317.74	1.11	3.56
C195 MN	.62	.49	0	181.03	0	134.19	.47	1.5
(N)	24	24	0	24	0	24	24	24

*METHOD 1 CLINKER RATE (TONS/HR) - 37

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 13.25
(TIME WEIGHTED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 46.77

EMISSION FACTORS

MMBTU / TON CLINKER = 4.66
LBS DRY FEED / MMBTU = 737
CO2 SCF / MMBTU = 2270
TOT SCF / MMBTU = 11969
NO LBS / SCF (3% O2) = .88 E-04
NO LBS / MMBTU = 1.24
NO LBS / TON CLINKER = 5.76

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 9-30-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.78**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
900	2.6	28.9	--	1054	--	744	5.1	8.81
915	2.7	29.2	--	1079	--	767	4.88	8.7
930	2.4	29.1	--	1021	--	719	5.15	8.62
945	2.7	29.1	--	1073	--	762	4.92	8.72
1000	2.6	29.4	--	1146	--	816	4.86	9.22
1015	2.6	28.4	--	950	--	655	5.35	8.27
1030	2.4	29.1	--	741	--	522	5.15	6.25
1045	2	29.1	--	683	--	476	5.47	6.06
1100	1.9	29	--	611	--	424	5.61	5.54
1115	2.7	27.8	--	677	--	470	5.6	6.12
1130	2.2	28.6	--	710	--	493	5.58	6.4
1145	2.6	28.6	--	706	--	496	5.25	6.05
1200	2.5	27.9	--	742	--	514	5.72	6.83
1215	2.7	27.3	--	913	--	629	5.9	8.63
1230	2.7	28.2	--	918	--	642	5.38	8.03
1245	2.3	28.9	--	830	--	581	5.33	7.21
1300	2.8	28.2	--	935	--	656	5.29	8.07
1315	2.6	28.9	--	997	--	704	5.1	8.34
1330	2.7	28	--	1044	--	728	5.49	9.28
1345	2.5	26.7	--	968	--	657	6.52	9.96
1400	2.5	26.6	--	893	--	605	6.59	9.28
1415	2.6	26.9	--	847	--	578	6.27	8.43
1430	2.6	25.6	--	777	--	519	7.3	8.82
1445	2.3	26.2	--	722	--	484	7.15	8.04
1500	2.4	26.4	--	753	--	507	6.86	8.1
1515	2.5	26.4	--	939	--	634	6.75	9.95
1530	2.8	25.3	--	1049	--	701	7.32	11.93

STATISTICAL DATA

MEAN	2.5	27.9	0	881	0	611	5.77	8.14
STD DEV	.22	1.23	0	151.14	0	109.69	.77	1.46
C195 MN	.09	.49	0	59.8	0	43.4	.31	.58
(N)	27	27	0	27	0	27	27	27

*METHOD 1 CLINKER RATE (TONS/HR) - 37

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.99
(TIME WEIGHTED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 45.85

EMISSION FACTORS

MMBTU / TON CLINKER = 4.7
LBS DRY FEED / MMBTU = 731
CO2 SCF / MMBTU = 2250
TOT SCF / MMBTU = 11949
NO LBS / SCF (3% O2) = 1.05 E-04
NO LBS / MMBTU = 1.47
NO LBS / TON CLINKER = 6.89

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : KVB GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-3-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.81**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
845	3.6	26.6	--	1364	--	950	5.5	12.14
900	3	26.3	--	1303	--	889	6.28	12.98
915	3.3	26	--	1353	--	925	6.18	13.29
930	3.1	26.3	--	1368	--	936	6.17	13.43
945	3.1	26.9	--	1161	--	802	5.78	10.78
1000	2.5	27.8	--	891	--	616	5.78	8.28
1015	2.7	27.6	--	841	--	582	5.72	7.74
1030	2.3	27.9	--	842	--	580	5.9	7.96
1045	2.1	29.5	--	896	--	630	5.19	7.6
1100	2.1	29.1	--	852	--	595	5.39	7.47
1115	2.3	26.9	--	1068	--	724	6.59	11.08
1130	2.6	27.3	--	1086	--	746	6	10.41
1145	2.7	25.7	--	1152	--	773	7.09	12.74
1200	2.2	27	--	1007	--	682	6.62	10.49
1215	2.7	26.6	--	895	--	609	6.38	9.04
1230	2.2	28.7	--	1023	--	712	5.52	9.15

STATISTICAL DATA

MEAN	2.7	27.3	0	1069	0	734	6.01	10.29
STD DEV	.46	1.11	0	195.95	0	132.68	.51	2.17
C19.5 MN	.24	.39	0	104.39	0	70.68	.27	1.15
(IN)	16	16	0	16	0	16	16	16

*METHOD 1 CLINKER RATE (TONS/HR) - 36

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 13.84
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 48.01

EMISSION FACTORS

MMBTU / TON CLINKER = 4.5
 LBS DRY FEED / MMBTU = 762
 CO2 SCF / MMBTU = 2348
 TOT SCF / MMBTU = 12047
 NO LBS / SCF (3% O2) = 1.28 E-04
 NO LBS / MMBTU = 1.8
 NO LBS / TON CLINKER = 8.08

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EMB GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EMB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-4-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.85**
 W2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
745	4.2	25	--	881	--	606	5.94	8.37
800	3.7	25.8	--	979	--	674	5.9	9.26
845	2.6	26.5	26	1307	10	886	6.56	13.52
900	3	27.5	33	1493	14	1040	5.51	13.32
915	2.4	28.5	34	1593	14	1111	5.47	14.12
1030	1.6	28.9	38	695	15	478	5.93	6.6
1045	1	30.5	325	673	124	468	5.53	6.04
1100	2.5	28	35	1161	14	805	5.66	10.6
1115	3.1	27.5	35	1623	15	1133	5.42	14.29
1130	3.5	27.4	66	1675	29	1180	5.14	14.1
1145	2.7	29.1	32	1626	14	1155	5.32	13.22
1200	2.9	28	62	1589	26	1113	5.32	13.76
1215	3.1	28.2	32	1418	14	1002	5.05	11.77
1230	2.7	30.1	36	1093	16	790	4.49	8.24
1245	2.3	29.1	74	710	30	499	5.23	6.07
1300	2.1	28.7	120	505	48	351	5.61	4.57
1315	2.7	29	32	398	13	277	5.49	3.54
1330	2.3	28.7	33	309	13	216	5.44	2.73

STATISTICAL DATA

MEAN	2.7	28.1	63	1096	26	766	5.48	9.67
STD DEV	.74	1.37	73.86	466.43	28.01	328.55	.45	4.02
C195 MN	.37	.68	39.35	231.97	14.92	163.4	.23	.2
(N)	18	18	16	18	16	18	18	18

*METHOD 1 CLINKER RATE (TONS/HR) - 40

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.24
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 42.83

EMISSION FACTORS

MMBTU / TON CLINKER = 5.07
 LBS DRY FEED / MMBTU = 677
 CO2 SCF / MMBTU = 2085
 TOT SCF / MMBTU = 11784
 NO LBS / SCF (3% O2) = 1.31 E-04
 NO LBS / MMBTU = 1.8
 NO LBS / TON CLINKER = 9.13

NO ON A MASS BASIS IN TERMS OF W02 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-5-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.8**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
815	1	30.8	255	466	98	326	5.39	4.08
830	1.6	27.4	77	526	29	354	6.97	5.73
845	2.4	26.7	105	912	42	617	6.63	9.51
900	2.3	27.6	74	1343	30	920	6.1	13.05
915	2.3	26.7	35	1470	14	993	6.74	15.56
930	2.4	26.7	55	1553	22	1051	6.63	16.2
945	2.2	25.9	36	1648	14	1097	7.54	19.23
1000	1.9	26.8	94	1652	36	1108	7.12	18.33
1015	1.6	29.1	86	1766	34	1219	5.82	16.49
1030	1.8	29.6	57	1551	23	1085	5.37	13.55
1045	1.5	29.2	96	1340	37	924	5.85	12.56
1100	1.3	28.7	211	1252	80	853	6.34	12.58
1115	1.5	28.7	172	1068	66	731	6.15	10.45
1130	1	28.8	352	686	131	465	6.57	7.11
1145	1.6	26.1	149	755	55	498	8.16	9.44
1200	1.8	26.9	38	1118	15	749	7.15	12.45
1230	2.8	25.4	32	1758	13	1176	7.23	19.78
1245	1.9	26.7	176	1606	68	1075	7.2	18
1300	2.2	26.4	42	1728	16	1159	7.1	19.12
1315	2.6	26.8	32	1785	13	1216	6.34	17.93
1330	2.4	29.6	65	1661	27	1180	4.91	13.48
1345	2.3	29.1	89	1434	37	1007	5.23	12.23
1400	2.1	29.6	58	1043	24	735	5.14	8.78
1430	2.3	31.1	38	695	16	508	4.23	5
1445	2.3	30.3	75	718	31	515	4.68	5.6
1500	2.6	30.4	59	858	25	621	4.43	6.41
1515	2.1	29.9	43	985	18	698	5	8.1
1530	2.4	29.6	43	931	18	661	4.91	7.56

STATISTICAL DATA

MEAN	2	28.2	94	1225	37	841	6.1	12.08
STD DEV	.48	1.67	76.55	419.23	28.45	281.05	1.04	4.87
C195 MN	.19	.65	29.69	162.57	11.03	108.99	.4	1.89
(N)	28	28	28	28	28	28	28	28

*METHOD 1 CLINKER RATE (TONS/HR) - 35

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 14.04
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 48.76

EMISSION FACTORS

MMBTU / TON CLINKER = 4.43
 LBS DRY FEED / MMBTU = 775
 CO2 SCF / MMBTU = 2388
 TOT SCF / MMBTU = 12087
 NO LBS / SCF (3% O2) = 1.46 E-04
 NO LBS / MMBTU = 2.06
 NO LBS / TON CLINKER = 9.14

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-6-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.71**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)**

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3102	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
745	2.9	27.2	39	998	16	690	5.78	9.27
800	2.2	28.9	43	981	17	685	5.42	8.63
815	1.9	27.6	203	960	79	652	6.5	9.85
830	2.1	27.1	96	1108	38	750	6.65	11.6
845	1.9	0	110	1126	30	532	0	0
900	1.8	0	87	898	23	424	0	0
915	1.9	0	58	927	16	438	0	0
945	2.3	0	75	1331	21	629	0	0
1000	2.3	0	23	1557	6	736	0	0
1015	3.2	0	23	1186	7	560	0	0
1030	8.6	0	7	1051	3	497	0	0
1045	8.7	0	12	1117	5	528	0	0

STATISTICAL DATA

MEAN	3.3	27.7	65	1103	22	593	6.09	9.84
STD DEV	2.53	.83	55.2	187.76	20.89	112.24	.58	1.28
C195 MN	1.61	1.32	35.08	119.3	13.27	71.32	.93	2.03
(N)	12	4	12	12	12	12	4	4

*METHOD 1 CLINKER RATE (TONS/HR) - 35

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)**

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 11.58
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 40.9

EMISSION FACTORS

MMBTU / TON CLINKER = 5.22
 LBS DRY FEED / MMBTU = 657
 CO2 SCF / MMBTU = 2023
 TOT SCF / MMBTU = 11722
 NO LBS / SCF (3% O2) = 1.32 E-04
 NO LBS / MMBTU = 1.8
 NO LBS / TON CLINKER = 9.42

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : ENV GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : ENV GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-7-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.14**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1130	1.9	29.9	132	1162	53	819	5.15	9.8
1145	1.7	30.8	129	1699	52	1208	4.88	13.71
1200	1.2	30.8	218	878	85	617	5.24	7.52
1215	1.7	29.7	110	637	44	445	5.4	5.59
1230	1.8	29.6	140	467	56	327	5.37	4.08
1245	2.7	27.8	40	464	17	322	5.6	4.2
1300	1.2	29.3	174	435	66	298	6.05	4.2
1315	2.5	26.7	73	719	29	488	6.52	7.4
1330	4.3	25.4	74	951	34	661	5.57	8.57
1345	5.6	24.5	37	1005	19	714	4.9	8.14
1400	4.2	27.1	39	1081	18	773	4.73	8.5
1415	4.3	26.6	36	960	17	682	4.89	7.77
1430	3.7	27.3	36	1057	16	748	5.02	8.74
1445	3.6	27.6	37	879	17	623	4.95	7.18
1500	2.8	28.7	40	508	17	339	5.04	4.21

STATISTICAL DATA

MEAN	2.9	28.1	88	860	36	606	5.29	7.31
STD DEV	1.34	1.91	59.24	338.92	22.07	243.62	.49	2.61
CI95 MN	.74	1.06	32.81	187.71	12.22	134.93	.27	1.45
(N)	15	15	15	15	15	15	15	15

*METHOD 1 CLINKER RATE (TONS/HR) - 38

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.85
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 45.35

EMISSION FACTORS

MMBTU / TON CLINKER = 4.4
 LBS DRY FEED / MMBTU = 779
 CO2 SCF / MMBTU = 2401
 TOT SCF / MMBTU = 12100
 NO LBS / SCF (3% O2) = 1.03 E-04
 NO LBS / MMBTU = 1.45
 NO LBS / TON CLINKER = 6.39

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD CASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD CASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-10-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.62**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
845	3.5	24	27	1184	11	786	7.64	13.99
900	3.7	23.1	29	1140	12	749	8.35	14.55
915	3.4	23.4	30	1164	12	764	8.47	15.05
930	5.7	24.3	25	1109	13	787	4.92	9.02
945	2.7	30.3	34	1081	15	784	4.41	8.04
1000	1.9	31.8	108	758	45	551	4.35	5.57
1015	1.8	28.6	47	685	18	471	5.93	6.51
1030	2.5	27.9	47	705	19	488	5.72	6.49
1045	2	28.8	47	692	19	480	5.64	6.3
1100	2.5	28	48	790	20	548	5.66	7.21
1115	2.5	26.8	41	839	17	570	6.44	8.55
1130	2.8	26.3	64	960	26	652	6.49	9.84
1145	3	25.8	39	1085	16	734	6.65	11.36
1200	2.9	25.9	39	1220	16	825	6.69	12.83
1315	1.6	34	79	869	33	650	3.79	5.74
1330	1.8	30	37	935	15	658	5.17	7.92
1345	1.8	30	38	902	15	635	5.17	7.64
1400	2	31.9	47	1026	20	749	4.25	7.41
1415	2.1	31.9	36	1139	15	834	4.19	8.13
1430	2.6	26.9	44	1193	18	814	6.27	11.87
1445	3.1	25.5	46	1236	19	834	6.78	13.15
1500	3.1	25.1	45	1267	18	849	7.12	14.07
1515	3	26.8	45	1220	19	839	5.94	11.59
1530	2.3	29	46	995	19	698	5.28	8.57
1545	1.9	29.9	47	571	19	402	5.15	4.81
1600	2.7	27.5	46	629	19	435	5.78	5.84
1615	2.7	27.3	46	604	19	416	5.9	5.71

STATISTICAL DATA

MEAN	2.7	27.8	45	963	19	667	5.86	9.18
STD DEV	.84	2.81	16.55	221.07	6.82	147.64	1.2	3.17
C195 MN	.33	1.11	6.55	87.47	2.7	58.42	.48	1.25
(N)	27	27	27	27	27	27	27	27

*METHOD 1 CLINKER RATE (TONS/HR) - 36

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 11.77	MMBTU / TON CLINKER = 5.08
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 675
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2078
CLINKER RATE (TON/HR) - 41.57	TOT SCF / MMBTU = 11777
	NO LBS / SCF (3% O2) = 1.15 E-04
	NO LBS / MMBTU = 1.58
	NO LBS / TON CLINKER = 8.04

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-11-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.39**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
845	2.3	27.7	26	1358	10	932	6.03	13.07
900	2.4	27.6	27	1455	11	1000	6	13.94
915	2.3	28.3	28	1405	11	974	5.66	12.83
930	2.5	27.8	28	1103	11	762	5.78	10.25
945	2.9	28	29	890	12	623	5.32	7.71
1000	3	29.7	34	956	15	692	4.45	7.16
1015	2.7	30.9	32	797	14	584	4.18	5.68
1030	2.9	30.1	32	959	14	697	4.36	7.06
1045	3.1	30.3	32	991	14	727	4.15	7.03
1100	3	30.7	32	905	14	667	4.07	6.32
1115	3.2	26.9	29	995	12	689	5.68	9.11
1130	3.2	26.6	27	1003	11	691	5.87	9.44
1145	3.4	27.6	28	1003	12	707	5.11	8.41
1200	3.2	28.7	29	1049	13	750	4.74	8.26
1215	3.3	29.6	29	958	13	698	4.29	6.97
1230	3.1	19.5	84	657	29	397	28.52	26.3
1245	3.2	26.7	34	870	14	601	5.81	8.11
1300	3.3	26.8	35	840	15	583	5.65	7.66
1330	4.4	26.8	28	850	13	608	4.71	6.67
1345	5.2	26.9	25	887	13	653	4.08	6.2
1400	5.3	26.4	25	892	13	653	4.22	6.4
1415	4.9	26.4	28	875	14	631	4.52	6.63
1430	4.1	26.2	32	880	15	617	5.28	7.58
1445	4.3	26.5	32	895	15	635	4.94	7.3
1500	4.3	26.8	32	920	15	656	4.79	7.32
1530	3.6	26.5	61	926	27	644	5.56	8.32
1545	3.7	26.7	34	966	15	676	5.35	8.41

STATISTICAL DATA

MEAN	3.4	27.5	33	974	14	687	5.89	8.89
STD DEV	.87	2.17	12.15	177.84	4.24	122.77	4.57	4.06
C195 MN	.35	.86	4.81	70.37	1.68	48.58	1.81	1.61
(N)	27	27	27	27	27	27	27	27

*METHOD 1 CLINKER RATE (TONS/HR) - 35

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION	EMISSION FACTORS
KILN FEEDER SPEED (RPM) - 11.8	MMBTU / TON CLINKER = 4.93
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 695
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2141
CLINKER RATE (TON/HR) - 41.69	TOT SCF / MMBTU = 11840
	NO LBS / SCF (3% O2) = 1.16 E-04
	NO LBS / MMBTU = 1.61
	NO LBS / TON CLINKER = 7.94

NO ON A MASS BASIS IN TERMS OF NO2 -

- * METHOD 1 : KVB CASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE
- * METHOD 2 : KVB CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)
- ** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-12-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.38**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
800	2.1	30	39	1780	16	1263	4.95	14.53
815	1.9	29.7	45	1623	18	1140	5.24	13.9
845	1.4	29.3	43	1500	17	1034	5.87	14.12
900	1.4	30.8	76	1558	30	1100	5.09	13.02
930	1.7	29.8	57	1528	23	1069	5.35	13.3
945	2.1	29.2	59	1259	24	881	5.34	10.94
1000	2	28.4	146	1230	58	848	5.87	11.58
1015	6.9	23.8	79	780	45	572	4.17	5.55
1030	7.2	23.5	19	598	11	441	4.07	4.17
1045	4.6	27.2	23	478	11	347	4.38	3.54
1100	3.2	29.8	20	427	9	311	4.28	3.1
1115	2.8	30.2	25	500	11	363	4.38	3.7
1130	1.9	31.8	25	585	10	425	4.35	4.3
1145	1.8	31.9	24	664	10	482	4.37	4.9
1200	3.6	29.6	22	792	10	583	4.1	5.55
1215	2.9	30.1	25	988	11	718	4.36	7.27
1230	4.9	26.5	25	944	12	683	4.47	7.1
1245	5.8	25.5	27	882	14	644	4.24	6.36
1300	5.3	26	28	829	14	601	4.4	6.15
1315	5.9	25.4	34	807	18	591	4.21	5.79
1330	4.7	26.8	37	760	18	549	4.48	5.73

STATISTICAL DATA

MEAN	3.5	28.3	42	977	19	697	4.67	7.84
STD DEV	1.89	2.48	29.7	416.88	12.39	285.56	.57	3.99
CI95 MN	.86	1.13	13.52	189.77	5.64	129.99	.26	1.82
(N)	21	21	21	21	21	21	21	21

*METHOD 1 CLINKER RATE (TONS/HR) - 44

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 12.01	MMBTU / TON CLINKER = 4.85
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 708
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2180
CLINKER RATE (TON/HR) - 42.39	TOT SCF / MMBTU = 11879
	NO LBS / SCF (3% O2) = 1.17 E-04
	NO LBS / MMBTU = 1.62
	NO LBS / TON CLINKER = 7.85

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : KVB GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-13-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.38**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
800	1.2	30.4	79	1187	30	828	5.44	10.48
815	1.4	29.7	96	1273	37	883	5.65	11.6
830	1.4	29.5	205	1241	79	858	5.76	11.49
915	1.4	28.9	62	980	24	671	6.12	9.55
930	1.5	29.7	99	916	39	637	5.56	8.24
945	2.1	30.9	54	893	23	643	4.56	6.83
1000	1.2	31.3	198	844	78	597	5.01	6.96
1015	2	30	52	805	21	570	5.02	6.65
1030	1.9	29.6	49	743	20	521	5.29	6.41
1045	2.1	29.2	46	721	19	505	5.34	6.27
1100	1.8	30.3	42	672	17	475	5.03	5.56
1115	2	30.3	37	729	15	518	4.89	5.89
1130	1.9	30.4	140	832	57	591	4.91	6.75
1145	1.9	30.4	51	989	21	703	4.91	8.03
1200	1.7	31.9	93	1051	38	761	4.43	7.85
1215	1.8	32.8	72	1122	30	827	4.06	7.81
1230	1.7	33.5	45	1137	19	846	3.89	7.66
1245	1.6	33.7	54	1218	23	907	3.88	8.19
1345	3.1	27.6	43	923	18	646	5.37	8.06
1400	2.9	26.9	40	828	17	569	5.97	7.9
1415	2.8	28.1	39	719	16	503	5.35	6.26
1430	2.7	29.2	36	623	15	443	4.88	5.03
1500	2.7	28.3	39	658	16	461	5.32	5.7
1515	2.7	28.4	37	747	16	524	5.27	6.42
1530	2.7	28.3	39	807	16	565	5.32	7

STATISTICAL DATA

MEAN	2	30	70	906	28	642	5.09	7.54
STD DEV	.57	1.72	47.07	198.04	18.14	145.42	.58	1.72
CI95 MN	.23	.71	19.43	81.75	7.49	60.03	.24	.71
(N)	25	25	25	25	25	25	25	25

*METHOD 1 CLINKER RATE (TONS/HR) - 40

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.98
(TIME WEIGHTED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 45.82

EMISSION FACTORS

MMBTU / TON CLINKER = 4.48
LBS DRY FEED / MMBTU = 765
CO2 SCF / MMBTU = 2356
TOT SCF / MMBTU = 12055
NO LBS / SCF (3% O2) = 1.08 E-04
NO LBS / MMBTU = 1.52
NO LBS / TON CLINKER = 6.83

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVB GASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVB GASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-14-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.35**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
745	1.5	29.9	300	1119	118	780	5.46	9.91
815	1.7	29	34	781	13	540	5.79	7.26
830	1.9	27	36	910	14	612	6.95	9.89
845	2	28.4	30	1017	12	701	5.87	9.57
900	2.1	30.2	32	975	13	694	4.86	7.84
915	1.6	30.9	155	948	62	674	4.9	7.68
930	1.4	29.7	31	824	12	571	5.65	7.51
945	1.2	29.2	49	865	19	592	6.12	8.43
1000	1.2	31	42	931	16	656	5.15	7.85
1015	1.8	31.2	321	780	122	546	5.35	6.79
1030	1.1	32.1	73	719	29	514	4.74	5.67
1045	1.8	31.2	91	582	37	418	4.64	4.51
1100	1.2	30.8	44	522	18	374	4.67	4.07
1115	1.6	32.7	84	410	35	300	4.21	2.94
1130	1.4	32	75	324	30	233	4.58	2.49
1145	2.1	31.7	276	264	107	187	4.97	2.16
1200	2.3	29.1	47	350	19	246	5.23	2.99
1215	1.9	30.5	54	419	22	298	4.87	2.38
1230	1.8	30	108	304	43	214	5.17	2.57
1245	2.1	28	43	524	18	366	5.4	4.6
1300	2.9	29	45	810	19	577	4.82	6.47
1315	2.6	28.9	40	954	17	673	5.1	7.98
1330	4.5	26.1	34	1016	16	720	4.99	8.35
1345	2.2	30	106	790	43	559	5.02	6.53
1400	2.2	28.5	76	373	30	257	5.81	3.48
1415	2.6	27.8	39	428	16	296	5.69	3.92
1430	2.2	29.2	79	477	32	335	5.26	4.09
1445	2.2	28.2	39	329	15	226	6	3.15
1500	3.1	26.9	34	324	14	224	5.78	3.01

STATISTICAL DATA

MEAN	2	29.6	83	658	33	461	5.28	5.69
STD DEV	.75	1.65	80.27	271.17	30.9	189.15	.57	2.49
CI95 MN	.29	.63	30.53	103.13	11.75	71.94	.22	.95
(N)	29	29	29	29	29	29	29	29

*METHOD 1 CLINKER RATE (TONS/HR) - 39

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.81
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 45.26

EMISSION FACTORS

MMBTU / TON CLINKER = 4.52
 LBS DRY FEED / MMBTU = 758
 CO2 SCF / MMBTU = 2336
 TOT SCF / MMBTU = 12035
 NO LBS / SCF (3% O2) = .79 E-04
 NO LBS / MMBTU = 1.1
 NO LBS / TON CLINKER = 5

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EMB CASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EMB CASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-24-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.64**
N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1000	2.3	29.2	15	969	6	682	5.18	8.22
1015	1.7	29.9	143	1067	57	748	5.3	9.22
1030	1.9	29.6	90	1094	36	767	5.29	9.44
1045	1.6	31.5	141	1077	57	773	4.65	8.36
1100	1.7	31.5	196	886	80	637	4.59	6.8
1115	2	29.2	138	865	56	604	5.42	7.61
1130	2.2	29.4	43	979	18	689	5.16	8.27
1145	1.9	29	114	1076	45	747	5.61	9.75
1200	2	29.3	111	1349	45	943	5.37	11.78
1215	2.1	29.7	146	1630	60	1151	5.09	13.62
1230	2.4	29.1	57	1804	24	1271	5.15	15.22
1245	2.5	29.1	39	1759	16	1242	5.07	14.66
1300	2.1	28.4	56	925	22	639	5.78	8.6
1315	1.8	28.5	60	330	24	227	6	3.16
1330	2	27.3	62	293	24	198	6.61	3.05
1345	3.1	26.8	37	395	16	272	5.84	3.7
1400	2.6	27.8	118	461	49	319	5.69	4.23
1415	2.8	28.5	68	602	29	424	5.14	5.07
1430	2.7	30.5	145	866	63	630	4.33	6.35
1445	2.6	32.3	68	550	30	412	3.78	3.62
1500	2.1	32.8	43	324	19	241	3.89	2.18

STATISTICAL DATA

MEAN	2.2	29.5	90	919	37	648	5.19	7.76
STD DEV	.4	1.53	48.61	459.22	19.83	319.12	.67	3.84
CI95 MN	.18	.7	22.13	206.31	9.02	145.26	.31	1.75
(N)	21	21	21	21	21	21	21	21

*METHOD 1 CLINKER RATE (TONS/HR) - 41

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 14.5
(TIME WEIGHTED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 49.7

EMISSION FACTORS

MMBTU / TON CLINKER = 4.26
LBS DRY FEED / MMBTU = 805
CO2 SCF / MMBTU = 2479
TOT SCF / MMBTU = 12178
NO LBS / SCF (3% O2) = 1.1 E-04
NO LBS / MMBTU = 1.56
NO LBS / TON CLINKER = 6.65

NO ON A MASS BASIS IN TERMS OF NO2 -

- * METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE
- * METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)
- ** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 10-25-1983

TEST CONDITION - AS FOUND COAL FLOW RATE (TON/HR) - 8.61**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1015	2.2	29.6	49	349	20	247	5.06	2.9
1030	2.3	29.1	54	324	22	228	5.23	2.77
1045	3.1	26	47	556	20	378	6.39	5.62
1100	3.1	26	47	516	20	351	6.39	5.22
1115	3	26.9	40	778	17	536	5.87	7.32
1130	3.2	26.2	44	1334	19	913	6.14	13.04
1145	3.3	26.7	44	1487	19	1029	5.71	13.68
1200	2.9	27.9	49	1594	21	1115	5.37	13.92
1215	2.7	29	50	1407	21	997	4.97	11.53
1230	2.1	29.3	84	633	34	444	5.29	5.46
1245	2.1	28.6	56	502	22	348	5.67	4.59
1300	2.4	27.5	65	1010	26	693	6.06	9.77
1315	1.5	28.5	168	1226	64	836	6.28	12.22
1330	2.1	28.2	119	1438	47	990	5.9	13.6
1345	2.6	28.1	51	1888	21	1314	5.52	16.86
1400	2.1	29.5	54	1543	22	1086	5.19	13.1
1415	2.4	29.1	141	770	58	542	5.15	6.5

STATISTICAL DATA

MEAN	2.5	28	68	1021	28	709	5.66	9.3
STD DEV	.5	1.25	37.82	498.95	14.42	347.87	.48	4.48
CI95 MN	.26	.64	19.44	256.55	7.41	178.86	.25	2.3
(N)	17	17	17	17	17	17	17	17

*METHOD 1 CLINKER RATE (TONS/HR) - 37

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 11.12	MMBTU / TON CLINKER = 5.37
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 639
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 1967
CLINKER RATE (TON/HR) - 39.3	TOT SCF / MMBTU = 11666
	NO LBS / SCF (3% O2) = 1.22 E-04
	NO LBS / MMBTU = 1.66
	NO LBS / TON CLINKER = 8.92

NO ON A MASS BASIS IN TERMS OF NO2 -

- * METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE
- * METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)
- ** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

APPENDIX F

NITROGEN INJECTION TEST SERIES

APPENDIX F-1

SAMPLE INVENTORY AND ANALYSIS

S I T E 4
EPA 806030. CLINKER SAMPLES

SAMPLE #	DATE 1983	TIME	SAMPLE LOCATION	KILN CONDITION	% FREE CAO	COMMENTS
C-69	11/15	730	CLINKER COOLER	BASLINE	0.17	
C-70	11/15	745	CLINKER COOLER	BASLINE	0.39	
C-71	11/15	800	CLINKER COOLER	BASLINE	0.17	SWITCH IN KILN FEED SILOS
C-72	11/15	815	CLINKER COOLER	BASLINE	0.19	
C-73	11/15	830	CLINKER COOLER	BASLINE	0.14	
C-74	11/15	900	CLINKER COOLER	BASLINE	0.14	
C-75	11/15	915	CLINKER COOLER	BASLINE	0.18	
C-76	11/15	930	CLINKER COOLER	BASLINE	0.15	
C-77	11/15	945	CLINKER COOLER	BASLINE	0.13	
C-78	11/15	1000	CLINKER COOLER	BASLINE	0.14	
C-79	11/15	1015	CLINKER COOLER	BASLINE	0.15	
C-80	11/15	1030	CLINKER COOLER	BASLINE	0.19	
C-81	11/15	1045	CLINKER COOLER	BASLINE	0.18	
C-82	11/15	1100	CLINKER COOLER	BASLINE	0.23	
C-83	11/15	1115	CLINKER COOLER	BASLINE	0.25	
C-84	11/15	1130	CLINKER COOLER	BASLINE	0.18	
C-85	11/15	1145	CLINKER COOLER	BASLINE	0.14	
C-86	11/15	1200	CLINKER COOLER	BASLINE	0.18	
C-87	11/15	1215	CLINKER COOLER	BASLINE	0.11	
C-88	11/15	1230	CLINKER COOLER	BASLINE	0.13	
C-89	11/15	1245	CLINKER COOLER	BASLINE	0.11	
C-90	11/15	1300	CLINKER COOLER	BASLINE	0.41	
C-91	11/15	1315	CLINKER COOLER	N2 INJECTION	0.24	N2 INJECTION STARTED AT 1307
C-92	11/15	1330	CLINKER COOLER	N2 INJECTION	0.12	N2 FLOW RATE UNSTEADY FROM
C-93	11/15	1345	CLINKER COOLER	N2 INJECTION	0.13	1307-1350
C-94	11/15	1400	CLINKER COOLER	N2 INJECTION	0.22	N2 FLOW RATE STEADY FROM
C-95	11/15	1415	CLINKER COOLER	N2 INJECTION	0.70	1350-1440 (98000 SCFH)
C-96	11/15	1430	CLINKER COOLER	N2 INJECTION	0.28	AVERAGE MILL OUTLET O2 = 17 %
C-97	11/15	1445	CLINKER COOLER	N2 INJECTION	0.21	
C-98	11/15	1500	CLINKER COOLER	BASLINE(REF.)	0.15	N2 OFF AT 1450
C-99	11/15	1515	CLINKER COOLER	BASLINE(REF.)	0.28	
C-100	11/15	1530	CLINKER COOLER	BASLINE(REF.)	0.18	
C-101	11/15	1545	CLINKER COOLER	BASLINE(REF.)	0.21	
C-102	11/15	1600	CLINKER COOLER	BASLINE(REF.)	0.24	
C-103	11/17	730	CLINKER COOLER	BASLINE(REF.)	0.20	
C-104	11/17	745	CLINKER COOLER	BASLINE(REF.)	0.16	
C-105	11/17	800	CLINKER COOLER	BASLINE(REF.)	0.17	
C-106	11/17	815	CLINKER COOLER	N2 INJECTION	0.18	N2 INJECTION STARTED AT 807
C-107	11/17	830	CLINKER COOLER	N2 INJECTION	0.19	MILL OUTLET O2 = 15.5 %
C-108	11/17	845	CLINKER COOLER	N2 INJECTION	0.17	MILL OUTLET O2 = 15.5 %
C-109	11/17	900	CLINKER COOLER	N2 INJECTION	0.15	MILL OUTLET O2 = 15.9 %
C-110	11/17	915	CLINKER COOLER	N2 INJECTION	0.18	MILL OUTLET O2 = 15.9 %
C-111	11/17	930	CLINKER COOLER	N2 INJECTION	0.17	MILL OUTLET O2 = 15.9 %
C-112	11/17	945	CLINKER COOLER	N2 INJECTION	0.14	MILL OUTLET O2 = 16.0 %
C-113	11/17	1000	CLINKER COOLER	N2 INJECTION	0.19	MILL OUTLET O2 = 15.8 %
C-114	11/17	1015	CLINKER COOLER	N2 INJECTION	0.18	MILL OUTLET O2 = 15.7 %
C-115	11/17	1030	CLINKER COOLER	N2 INJECTION	0.22	MILL OUTLET O2 = 15.4 %
C-116	11/17	1045	CLINKER COOLER	N2 INJECTION	0.16	MILL OUTLET O2 = 15.1 %
C-117	11/17	1100	CLINKER COOLER	N2 INJECTION	0.15	MILL OUTLET O2 = 14.7 %
C-118	11/17	1115	CLINKER COOLER	N2 INJECTION	0.20	MILL OUTLET O2 = 14.4 %
C-119	11/17	1130	CLINKER COOLER	N2 INJECTION	0.21	MILL OUTLET O2 = 14.5 %
C-120	11/17	1145	CLINKER COOLER	BASLINE	0.18	N2 OFF AT 1131
C-121	11/17	1200	CLINKER COOLER	BASLINE	0.24	
C-122	11/17	1215	CLINKER COOLER	BASLINE	0.19	
C-123	11/17	1230	CLINKER COOLER	BASLINE	0.37	
C-124	11/17	1245	CLINKER COOLER	BASLINE	0.20	
C-125	11/17	1300	CLINKER COOLER	AS FOUND	0.61	KILN IN THE HOLE
C-126	11/17	1315	CLINKER COOLER	AS FOUND	2.17	
C-127	11/17	1330	CLINKER COOLER	AS FOUND	3.22	
C-128	11/17	1345	CLINKER COOLER	AS FOUND	1.52	REHEATING FRONT END
C-129	11/17	1400	CLINKER COOLER	AS FOUND	0.59	
C-130	11/17	1415	CLINKER COOLER	AS FOUND	0.25	
C-131	11/17	1430	CLINKER COOLER	AS FOUND	0.19	

SITE 4
EPA 806038. CLINKER SAMPLES

SAMPLE # -----	DATE 1984 -----	TIME -----	SAMPLE LOCATION -----	KILN CONDITION -----	KVB % FREE CAO -----	COMMENTS -----
C-166	4/17	1335	WEIGH BELT	BASELINE	.12/.12	
C-167	4/17	1355	WEIGH BELT	BASELINE	.12/.12	
C-168	4/17	1415	WEIGH BELT	BASELINE	.14/.15	
C-169	4/17	1450	WEIGH BELT	BASELINE	.12/.11	
C-170	4/17	1525	WEIGH BELT	BASELINE	.13/.11	
C-171	4/17	1550	WEIGH BELT	BASELINE	.13/.13	
C-172	4/17	1620	WEIGH BELT	BASELINE	.10/.10	
C-173	4/17	1640	WEIGH BELT	BASELINE	.10/.11	
C-174	4/17	1700	WEIGH BELT	BASELINE	.30/.31	
C-175	4/17	1730	WEIGH BELT	BASELINE	.10/.11	
C-176	4/17	1800	WEIGH BELT	N2 INJECTION	.24/.23	
C-177	4/17	1830	WEIGH BELT	N2 INJECTION	.15/.15	
C-178	4/17	1850	WEIGH BELT	N2 INJECTION	.15/.15	
C-179	4/17	1908	WEIGH BELT	N2 INJECTION	.10/.10	
C-180	4/17	1930	WEIGH BELT	N2 INJECTION	.10/.11	
C-181	4/17	2030	WEIGH BELT	N2 INJECTION	.15/.15	
C-182	4/17	2052	WEIGH BELT	N2 INJECTION	.08/.08	
C-183	4/17	2120	WEIGH BELT	N2 INJECTION	.08/.08	
C-184	4/17	2205	WEIGH BELT	N2 INJECTION	.15/.15	
C-185	4/17	2230	WEIGH BELT	N2 INJECTION	.06/.07	
C-186	4/17	2255	WEIGH BELT	N2 INJECTION	.15/.14	
C-187	4/17	2325	WEIGH BELT	DECREASE N2	.09/.08	
C-188	4/17	2350	WEIGH BELT	DECREASE N2	.12/.11	
C-189	4/18	0010	WEIGH BELT	BASELINE	.11/.10	
C-190	4/18	0030	WEIGH BELT	BASELINE	.13/.13	
C-191	4/18	0053	WEIGH BELT	BASELINE	.17/.17	

S I T E 4
EPA 806038. KILN FEED SAMPLES

SAMPLE NO.	DATE		SAMPLE LOCATION	KILN CONDITION	ANALYZED	FEED + COAL ASH	
	1983/1984	TIME				BURNABILITY FACTOR	BURNABILITY INDEX
F-44	11/15	1120	EAST SLIDE CHUTE	AS FOUND	N	-	-
F-45	11/15	1515	EAST SLIDE CHUTE	AS BASELINE	N	-	-
F-46	11/17	0720	EAST SLIDE CHUTE	AS BASELINE	Y	107.3	2.72
F-47	11/17	0800	EAST SLIDE CHUTE	N2 INJECT	Y	107.3	2.71
F-48	11/17	0828	EAST SLIDE CHUTE	N2 INJECT	Y	108.9	2.95
F-49	11/17	0900	EAST SLIDE CHUTE	N2 INJECT	Y	109.1	2.91
F-50	11/17	0930	EAST SLIDE CHUTE	N2 INJECT	Y	107.1	2.70
F-51	11/17	1000	EAST SLIDE CHUTE	N2 INJECT	Y	107.1	2.65
F-52	11/17	1030	EAST SLIDE CHUTE	N2 INJECT	Y	106.9	2.75
F-53	11/17	1100	EAST SLIDE CHUTE	N2 INJECT	Y	107.3	2.74
F-54	11/17	1130	EAST SLIDE CHUTE	N2 INJECT	Y	107.1	2.69
F-55	11/17	1200	EAST SLIDE CHUTE	BASELINE	Y	106.4	2.66
F-56	11/17	1230	EAST SLIDE CHUTE	BASELINE	Y	108.6	2.94
F-57	11/17	1300	EAST SLIDE CHUTE	BASELINE	Y	108.9	2.97
F-58	11/17	1330	EAST SLIDE CHUTE	BASELINE	Y	109.6	3.15
F-59	11/17	1400	EAST SLIDE CHUTE	BASELINE	Y	109.4	3.07
F-60	11/17	1430	EAST SLIDE CHUTE	BASELINE	Y	109.1	2.98
F-92	4/17	1420	WEST SLIDE CHUTE	BASELINE	Y	108.7	2.73
F-93	4/17	1515	WEST SLIDE CHUTE	BASELINE	Y	112.1	3.31
F-94	4/17	1545	WEST SLIDE CHUTE	BASELINE	Y	114.2	3.35
F-95	4/17	1630	WEST SLIDE CHUTE	BASELINE	Y	108.4	2.50
F-96	4/17	1700	WEST SLIDE CHUTE	BASELINE	Y	109.3	2.77
F-97	4/17	1730	WEST SLIDE CHUTE	BASELINE	Y	106.9	2.36
F-98	4/17	1800	WEST SLIDE CHUTE	N2 INJECT	Y	107.3	2.44
F-99	4/17	1830	WEST SLIDE CHUTE	N2 INJECT	Y	105.9	2.31
F-100	4/17	1900	WEST SLIDE CHUTE	N2 INJECT	Y	105.8	2.23
F-101	4/17	1930	WEST SLIDE CHUTE	N2 INJECT	Y	106.7	2.58
F-102	4/17	2000	WEST SLIDE CHUTE	N2 INJECT	Y	110.0	3.08
F-103	4/17	2030	WEST SLIDE CHUTE	N2 INJECT	Y	109.5	3.05
F-104	4/17	2100	WEST SLIDE CHUTE	N2 INJECT	Y	109.8	2.88
F-105	4/17	2130	WEST SLIDE CHUTE	N2 INJECT	Y	110.0	3.14
F-106	4/17	2200	WEST SLIDE CHUTE	N2 INJECT	Y	108.6	2.89
F-107	4/17	2230	WEST SLIDE CHUTE	N2 INJECT	Y	110.3	3.26
F-108	4/17	2305	WEST SLIDE CHUTE	N2 INJECT	Y	112.8	3.41
F-109	4/17	2340	WEST SLIDE CHUTE	N2 INJECT	Y	104.1	2.35
F-110	4/18	2405	WEST SLIDE CHUTE	BASELINE	Y	104.3	2.45

FORMULAE FOR FEED BURNABILITY:

$$\begin{aligned} \text{LINE SATURATION FACTOR} &= \frac{100 \text{ CAO}}{2.8 \text{ SI02} + 1.1 \text{ AL2O3} + 0.7 \text{ FE2O3}} \\ \text{SILICA RATIO (SR)} &= \frac{\text{SI02}}{\text{AL2O3} + \text{FE2O3}} \\ \text{PERCENT FLUX} &= 1.13 \text{ C3A} + 1.35 \text{ C4AF} + \text{MGO} + \text{ALKALIES (NA2O + K2O)} \\ \text{BURNABILITY INDEX} &= \frac{\text{C3S}}{\text{C4AF} + \text{C3A}} \\ \text{BURNABILITY FACTOR} &= (\text{LSF}) + 10(\text{SR}) - 3(\text{MGO} + \text{ALKALIES}) \end{aligned}$$

APPENDIX F-2

KILN EMISSIONS AND OPERATIONS STRIPCHARTS

NO_x (0-2500 ppmv)

Material Temperature
(1900-2600°F)

Kiln Speed
(0-100 rph)

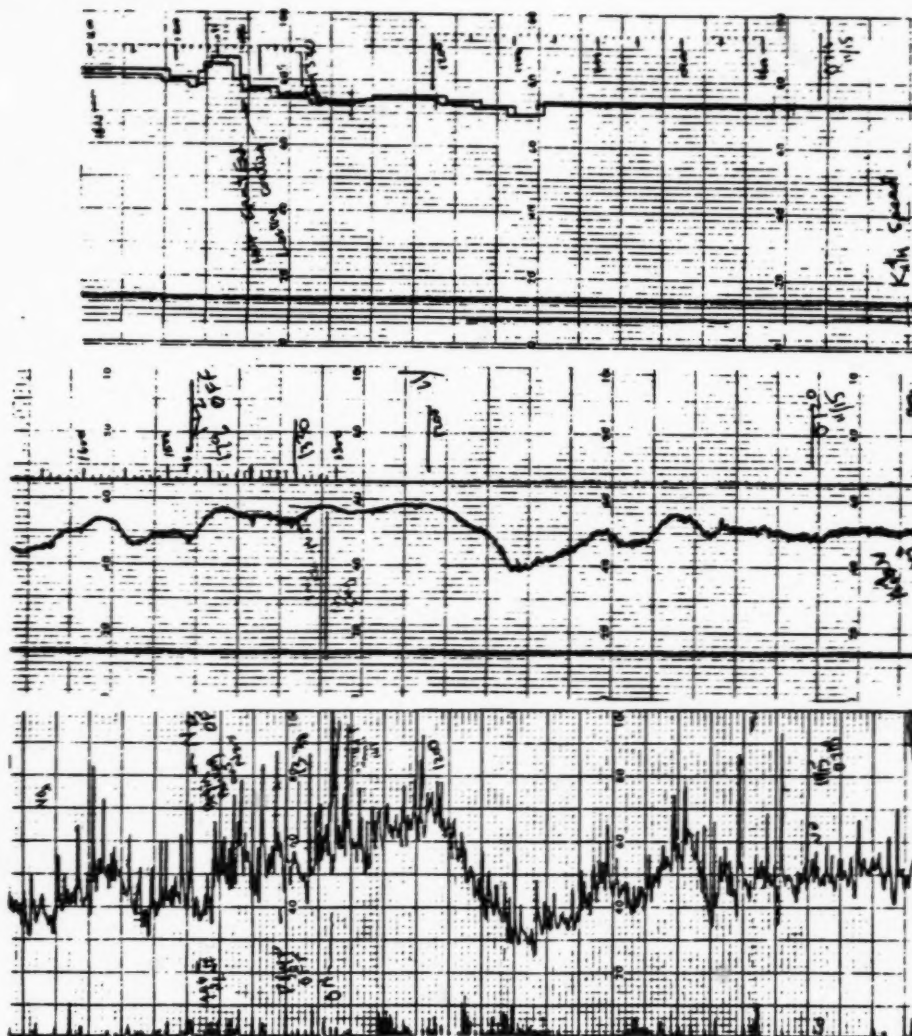


Figure F-1. November 15 (NO_x, Material Temp., Kiln Speed); 0600 - 1700 hrs

O₂, Dry (0-5%)

Undergrate Pressure
(0-15" H₂O)

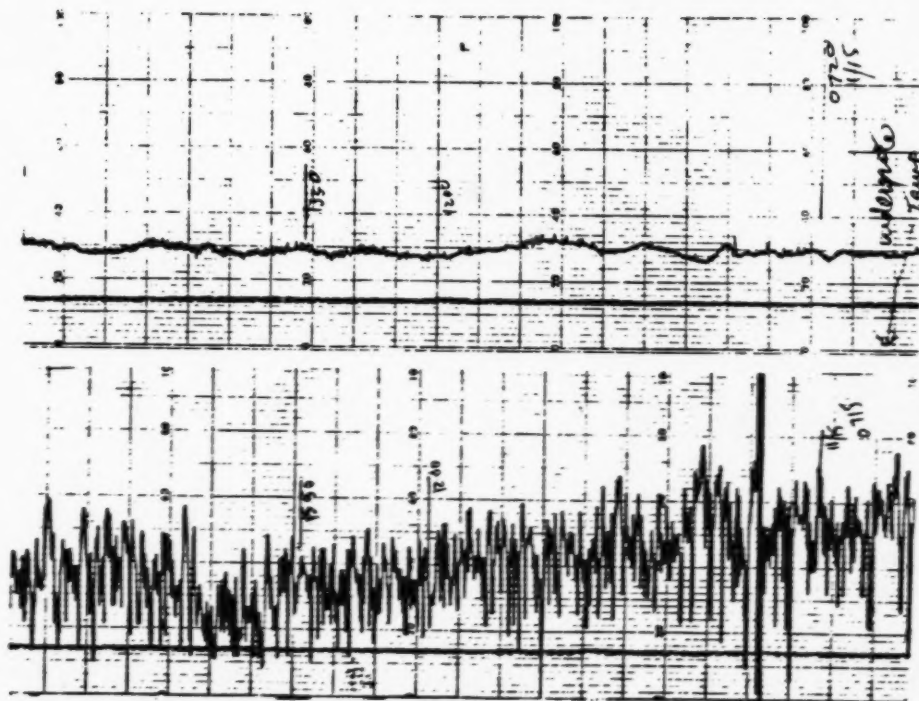


Figure F-2. November 15 (O₂, Undergrate Pressure);
0600 - 1700 hrs

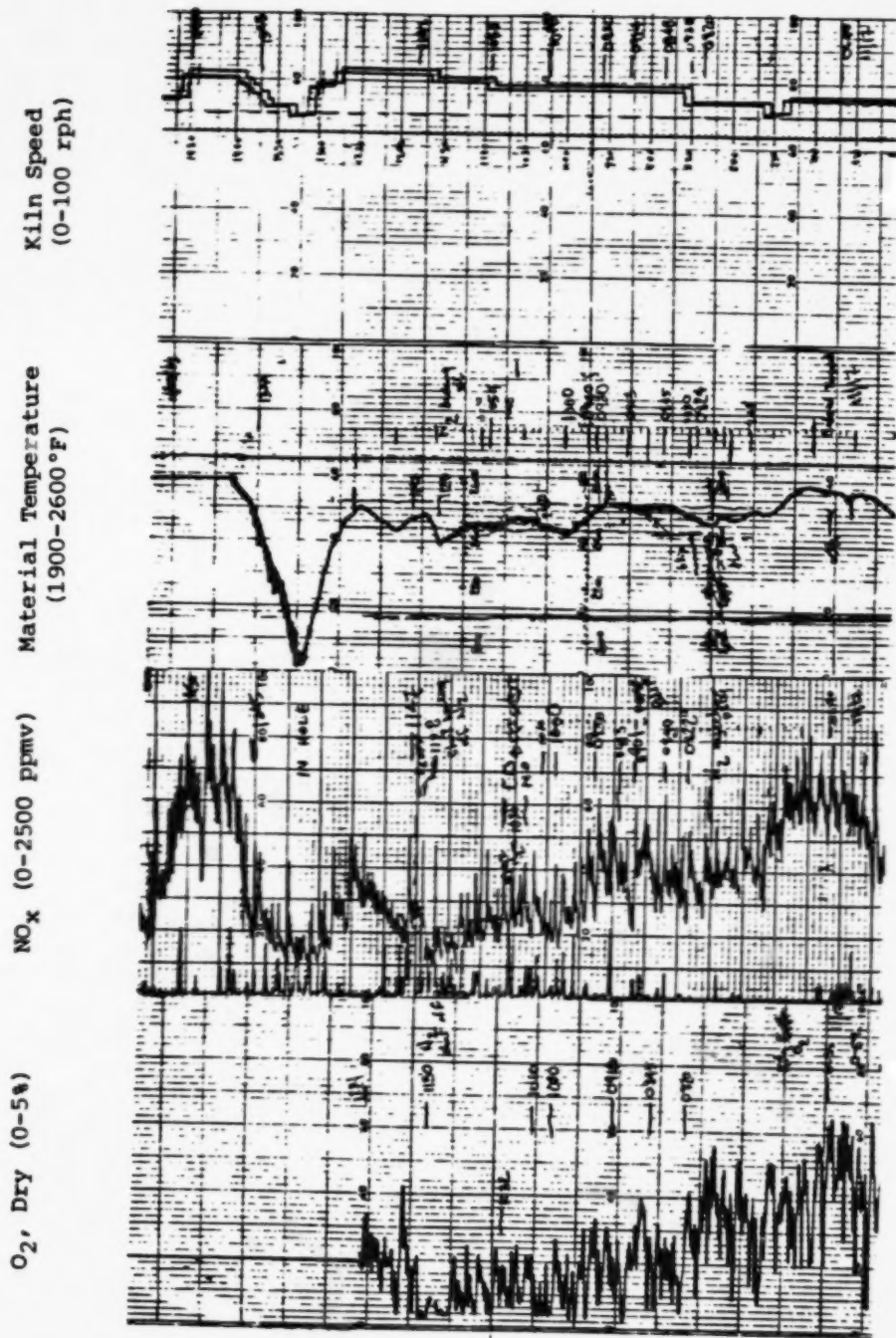


Figure F-3. November 17 (O₂, NO_x, Material Temp., Kiln Speed); 0600 - 1500 hrs

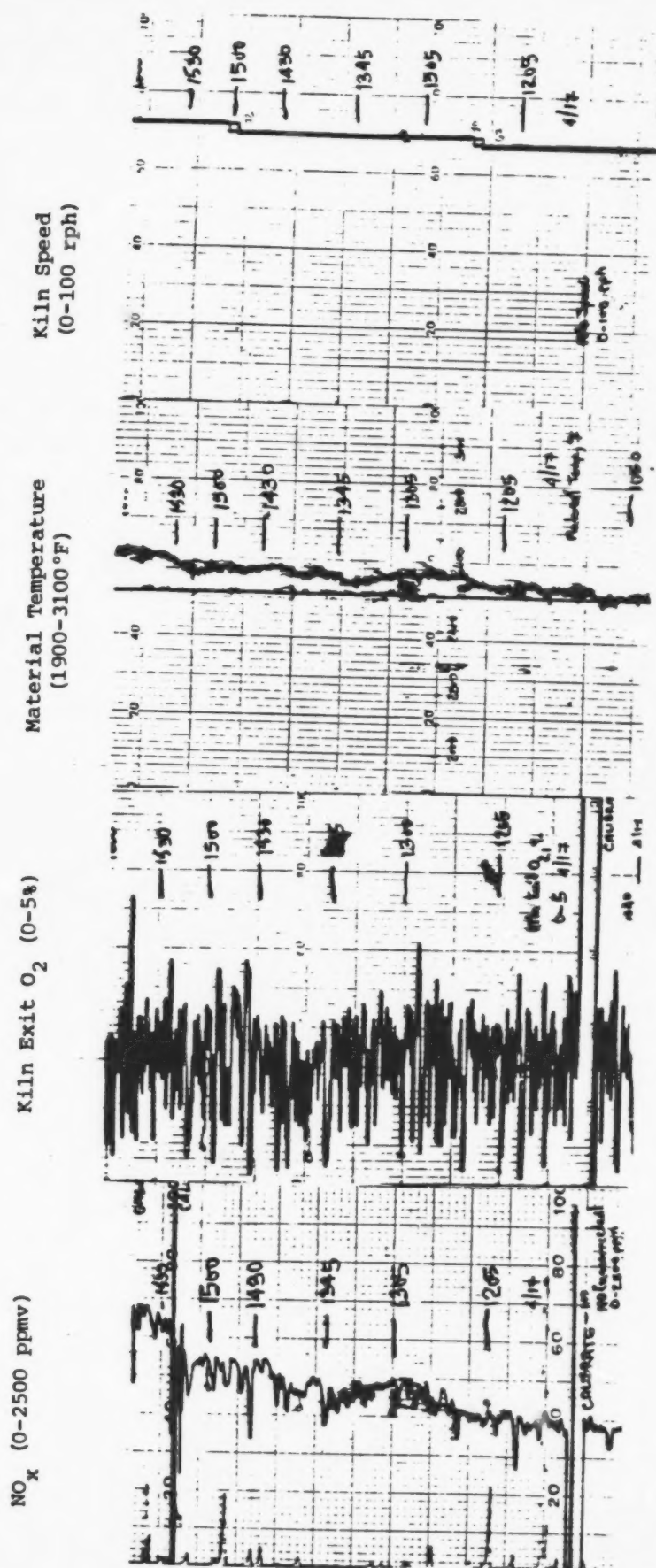


Figure F-4. April 17 (NO_x , Kiln Exit O_2 , Material Temp., Kiln Speed); 1040 - 1600 hrs

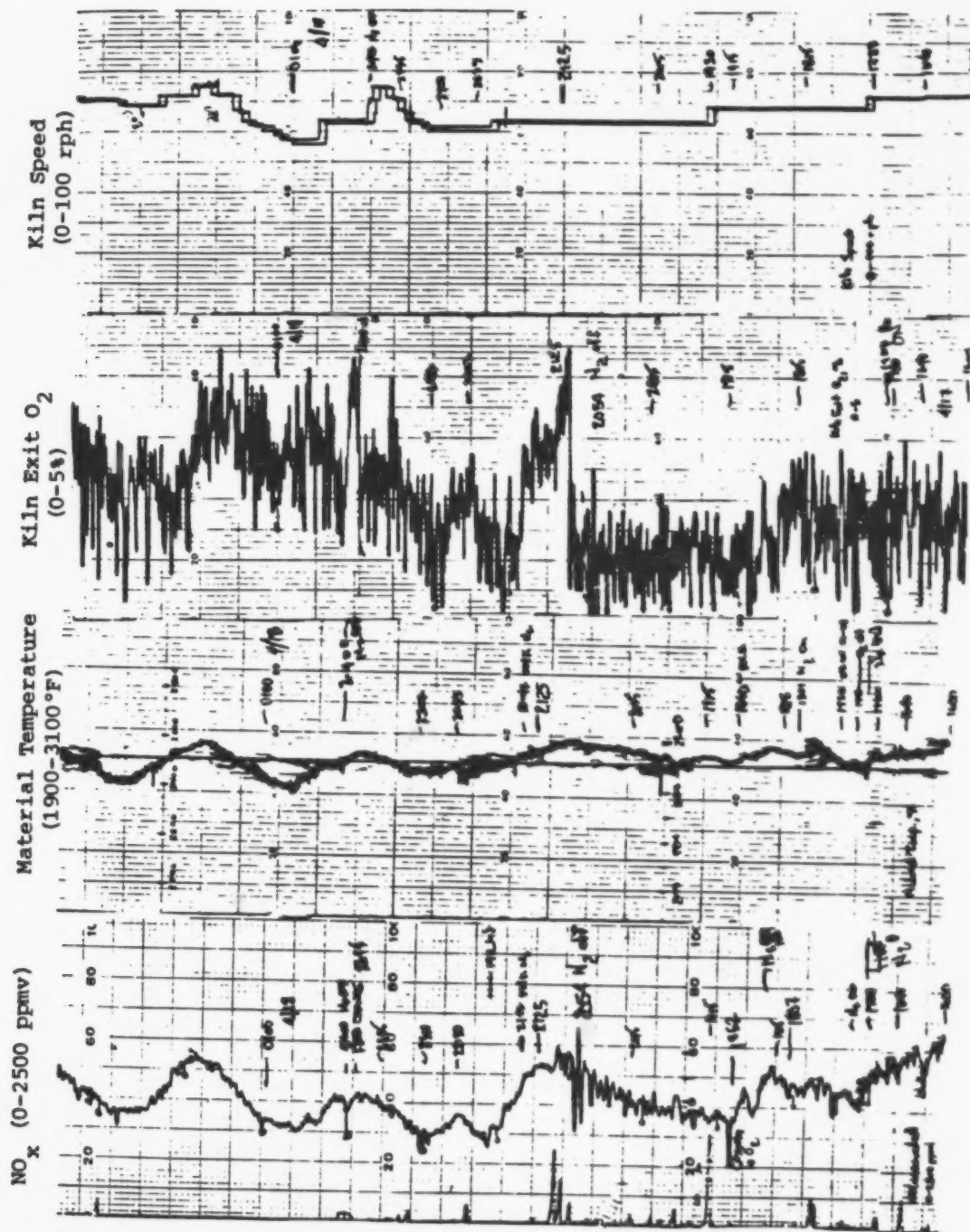


Figure F-5. April 17-18 (NO_x , Material Temp., Kiln Exit O_2 , Kiln Speed); 1600 - 0345 hrs

Reproduced from
best available copy.

Kiln Drive Load (50% Scale = Zero
load dev. at given kiln speed)

Undergrate Pressure (0-15" H₂O)

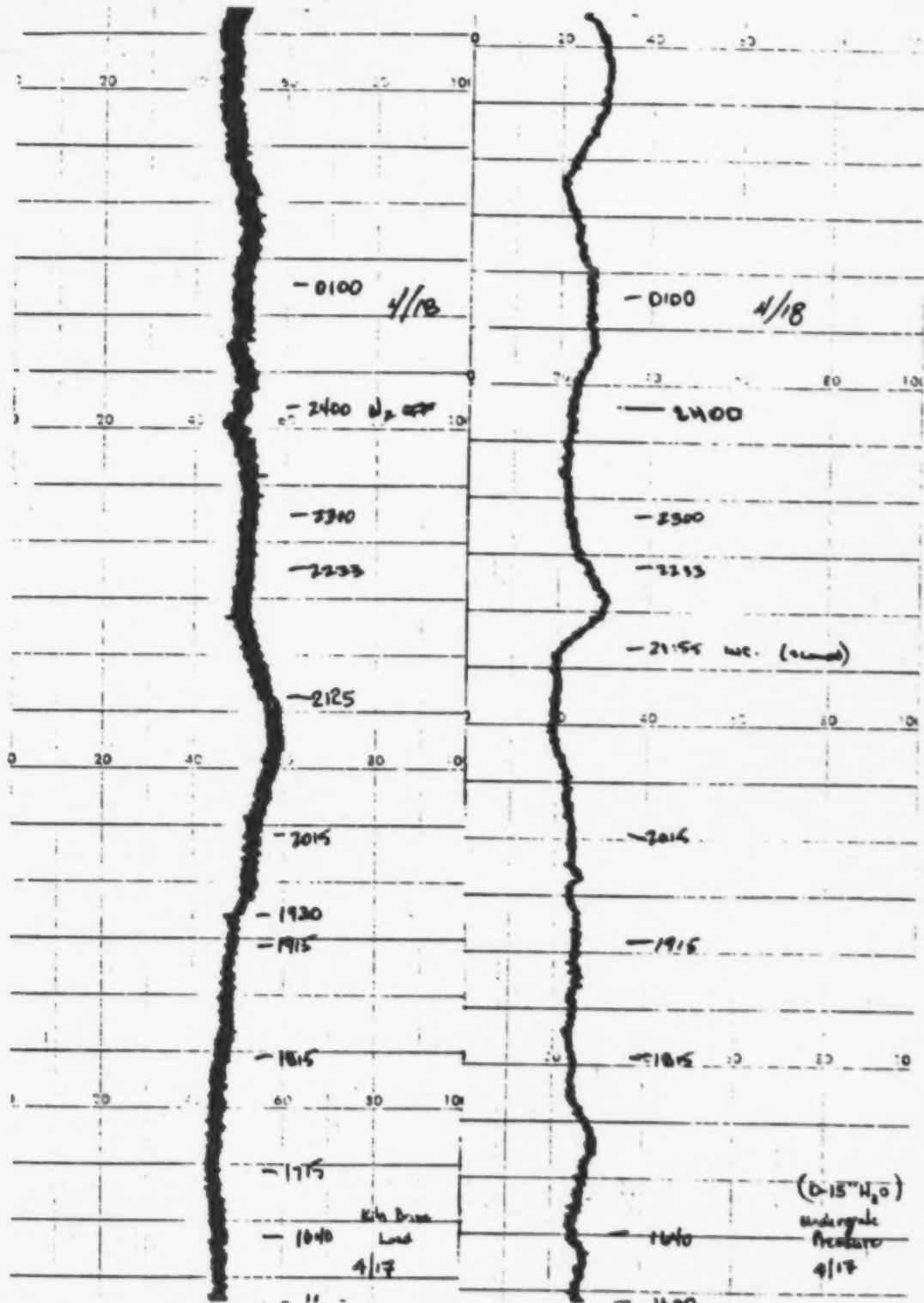


Figure F-6. April 17-18 (Kiln Drive Load, Undergrate Pressure); 1600 - 0345 hrs

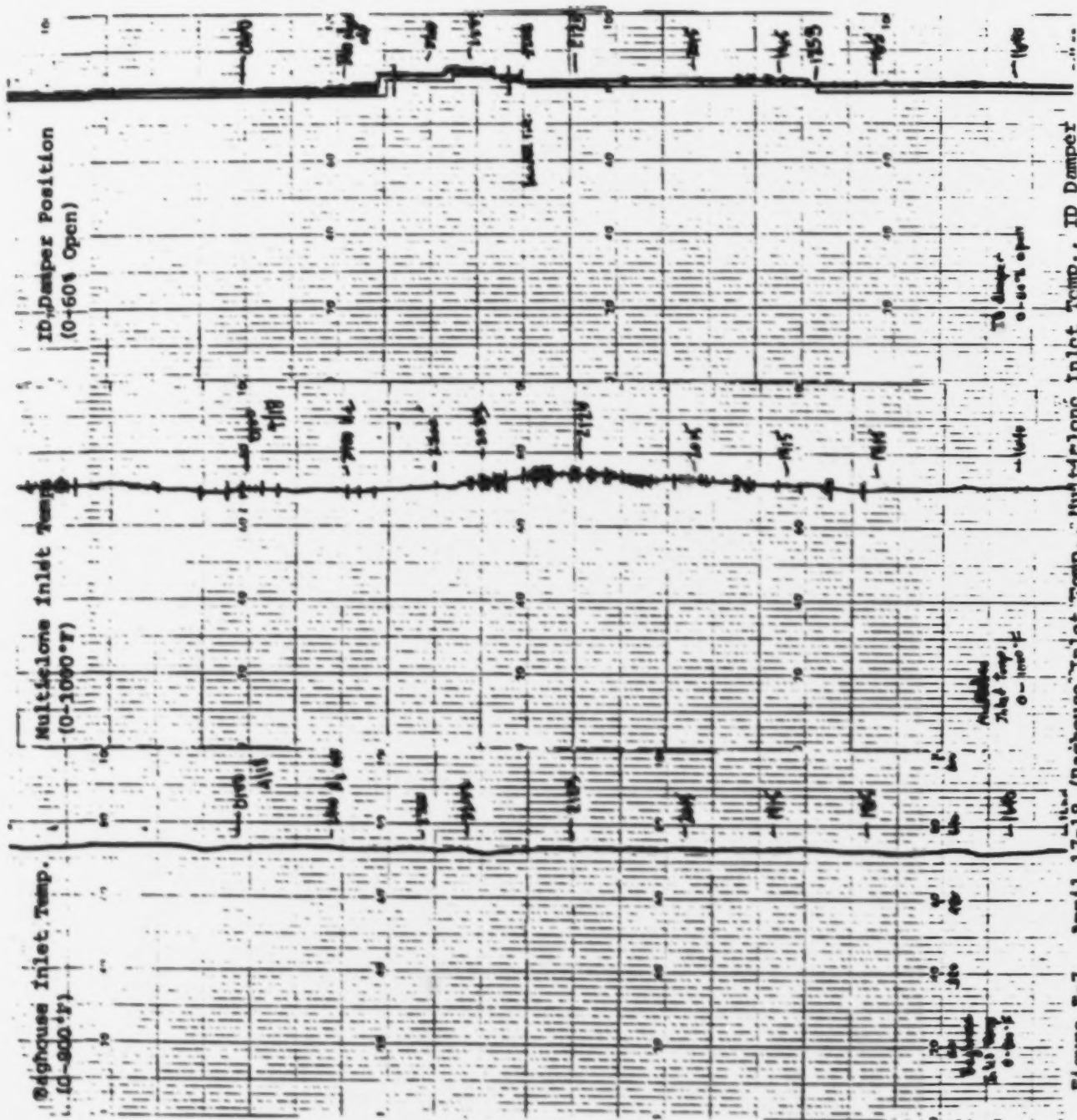


Figure F-7. April 17-18 (Baghouse Inlet Temp., Multicelone Inlet Temp., ID Damper Position): 1600 - 0345 hr

Coal Feed Rate (0-15 tons/hr)

Coal Mill Inlet Pressure (0-10" H₂O)
Coal Mill Outlet Pressure (0-25" H₂O)

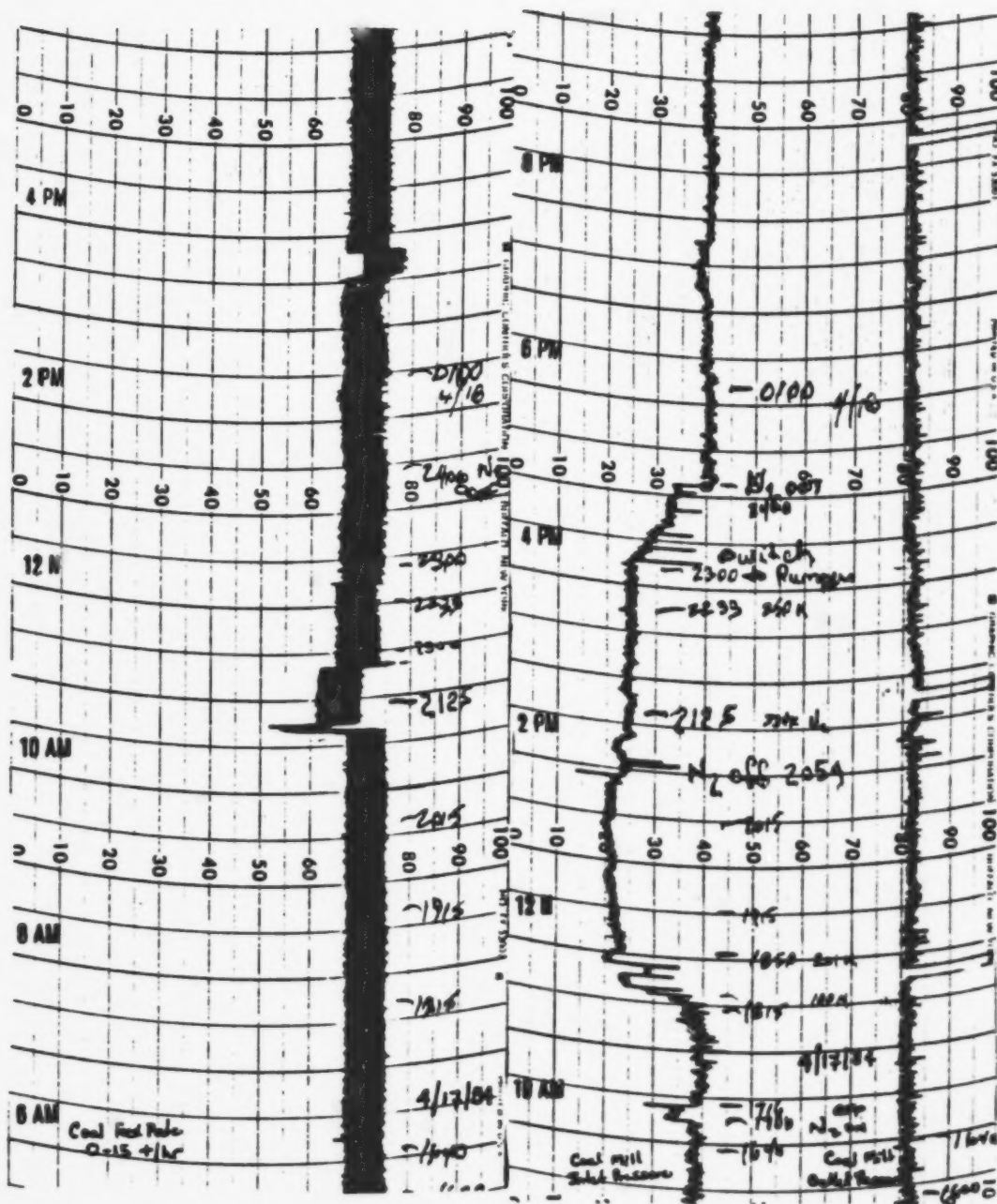


Figure F-8. April 17-18 (Coal Feed Rate, Coal Mill Inlet Pressure, Coal Mill Outlet Pressure); 1600 - 0345 hrs

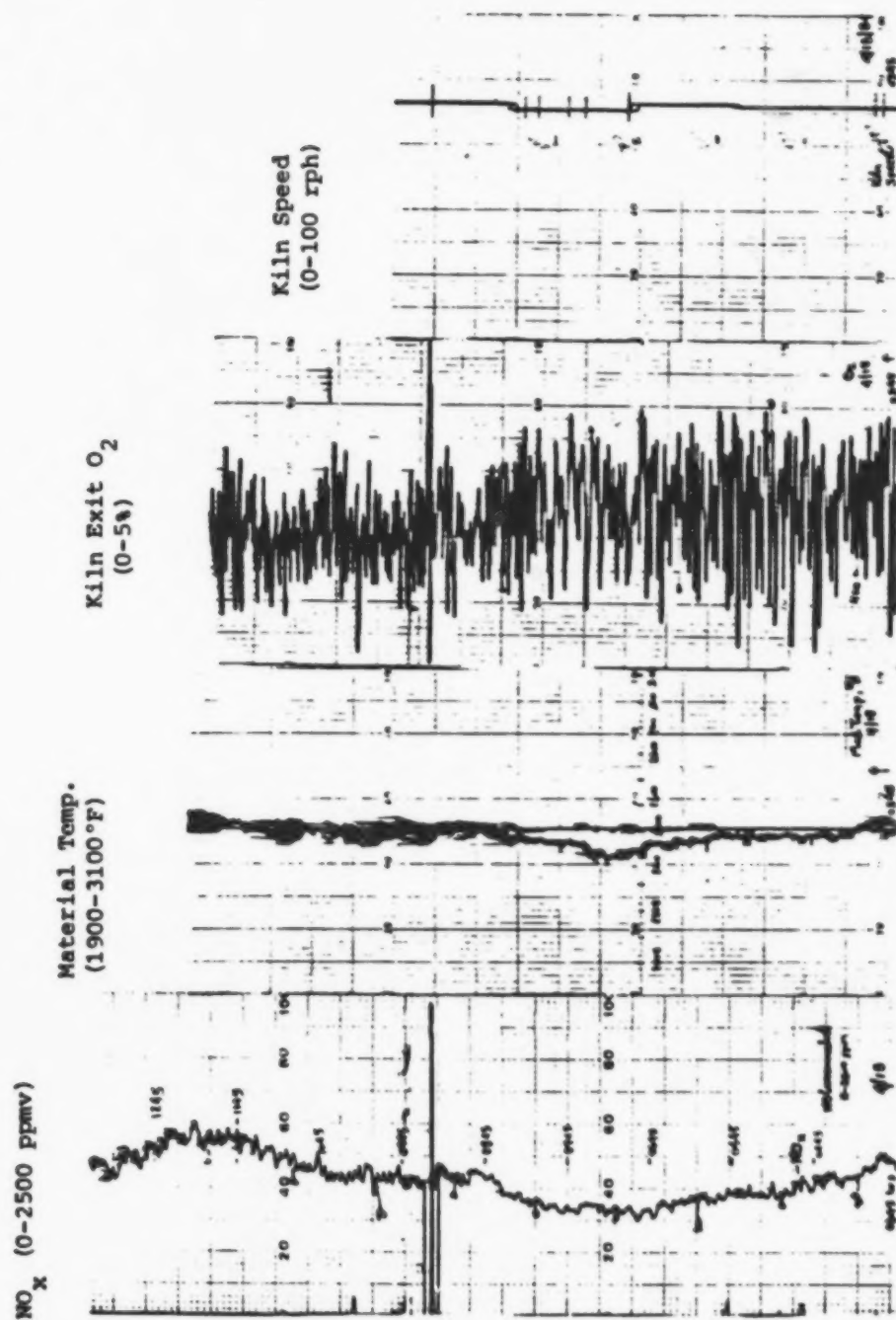


Figure F-9. April 18 (NO_x , Material Temp., Kiln Exit O_2 , Kiln Speed)

APPENDIX F-3

EMISSIONS DATA

November 15
November 17
April 17 - 18

SITE 4 ROTARY KILN

DATE - 11-15-1983

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.98**
N2 FLOW RATE (SCFH) - 98000 COAL HEAT VALUE(BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1351-1354	1.1	28.4	46	1185	17	800	6.75	12.57
1355-1402	.8	29.1	370	1050	136	712	6.56	10.87
1403-1406	1	28.9	375	1098	139	745	6.5	11.27
1407-1410	1	30	163	1172	62	809	5.82	10.95
1411-1414	1.5	28.6	97	1246	37	851	6.21	12.31
1415-1418	.7	29.8	419	1068	154	730	6.2	10.53
1419-1422	1	30.1	459	1090	174	754	5.76	10.1
1423-1426	1.1	29.6	128	1141	48	785	5.96	10.88
1427-1430	1.1	30	119	1102	45	762	5.73	10.17
1431-1434	1.1	29.8	288	994	109	686	5.85	9.32
1435-1438	.8	30.8	380	842	143	586	5.55	7.56
1439-1442	.9	30.1	186	873	70	602	5.85	8.19

STATISTICAL DATA

MEAN	1	29.6	253	1072	95	735	6.06	10.39
STD DEV	.21	.71	144.37	120.15	53.69	79.6	.38	1.48
CI95 MN	.13	.45	91.73	76.34	34.11	50.57	.24	.94
(N)	12	12	12	12	12	12	12	12

*METHOD 1 CLINKER RATE (TONS/HR) - 36

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 16.81	MMBTU / TON CLINKER = 3.7
(TIME WEIGHTED AVERAGE)	LBS DRY FEED / MMBTU = 927
FEEDER REVS/TON CLINKER - 17	CO2 SCF / MMBTU = 2855
CLINKER RATE (TON/HR) - 59.5	TOT SCF / MMBTU = 12554
	NO LBS / SCF (3% O2) = 1.28 E-04
	NO LBS / MMBTU = 1.88
	NO LBS / TON CLINKER = 6.95

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO,CO2,CO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO,O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-15-1983

TEST CONDITION - BASELINE
 N2 FLOW RATE (SCFH) - NONE
 COAL FLOW RATE (TON/HR) - 8.96**
 COAL HEAT VALUE (BTU/LB) - 12260

15 MIN DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 1)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	MMBTU / TON CLINKER	NO LB / TON CLINKER
1449-1452	1.6	29.5	302	1030	118	716	5.59	9.3
1453-1456	2	28.9	57	1088	23	756	5.58	9.82
1457-1459	1.4	30.5	84	944	33	663	5.23	8.07
1510-1513	1.7	30.1	125	942	50	662	5.2	8.01
1514-1517	1.5	29.6	57	886	22	615	5.62	8.04
1518-1521	1.2	30.4	187	781	72	545	5.44	6.89
1522-1524	1.5	29.3	40	852	16	589	5.79	7.92
1537-1540	2.4	28.2	32	1107	13	768	5.63	10.06
1541-1544	2.1	28.6	46	1074	18	744	5.67	9.81
1545-1548	1.8	29.1	42	1121	17	778	5.64	10.2
1549-1552	2.2	28.9	67	1157	27	808	5.42	10.18
1553-1556	2.1	30	250	1107	103	785	4.95	9.04
1557-1600	1.7	29.7	35	1085	14	758	5.4	9.52

STATISTICAL DATA

MEAN	1.8	29.4	102	1013	40	707	5.47	8.99
STD DEV	.35	.7	89.08	119.22	35.35	83.71	.23	1.08
C195 MN	.21	.42	53.84	72.05	21.37	50.59	.14	.65
(N)	13	13	13	13	13	13	13	13

*METHOD 1 CLINKER RATE (TONS/HR) - 40

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 16.81
 (TIME WEIGHTED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 59.04

EMISSION FACTORS

MMBTU / TON CLINKER = 3.72
 LBS DRY FEED / MMBTU = 922
 CO2 SCF / MMBTU = 2839
 TOT SCF / MMBTU = 12538
 NO LBS / SCF (3% O2) = 1.21 E-04
 NO LBS / MMBTU = 1.77
 NO LBS / TON CLINKER = 6.59

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 1 : EVD GASEOUS EMISSIONS DATA (NO, CO2, CO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (MEASURED BY PLANT INSTRUMENTATION)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE
COAL FLOW RATE (TON/HR) - 8.69**
COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
636-643	1.8	29	58	1597	25	1190	76	3.87	10.72
644-648	1.2	29.4	75	1552	31	1156	76	3.87	10.42
649-653	1.8	28.6	58	1720	25	1282	76	3.87	11.55
654-658	1.5	29.7	101	1622	42	1209	76	3.87	10.89
659-703	1.5	29.7	117	1588	49	1183	76	3.87	10.66
704-708	1.8	29.2	57	1634	24	1218	76	3.87	10.97
709-713	1.4	29.8	59	1451	25	1081	76	3.87	9.74
714-718	2.1	28.5	54	1394	23	1036	75	3.93	9.46
719-723	1.2	30.6	58	1166	24	859	72	4.09	8.17
724-728	.7	31.3	524	947	208	697	72	4.09	6.64
729-733	1.3	30.1	244	1080	100	798	73	4.03	7.48
734-747	1.5	30.5	69	1038	29	769	74	3.98	7.12
748-752	1.6	30	66	1024	28	759	74	3.98	7.02
753-757	1.7	29.1	62	995	26	737	74	3.98	6.82
758-802	1.8	29.1	64	995	27	737	74	3.98	6.82

STATISTICAL DATA

MEAN	1.5	29.6	111	1320	46	981	74.67	3.94	8.97
STD DEV	.34	.78	124.03	289.54	48.99	218.63	1.5	.08	1.85
C195 MN	.19	.43	68.7	160.36	27.13	121.09	.83	.05	1.03
(N)	15	15	15	15	15	15	15	15	15

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 15.31
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 54.03

EMISSION FACTORS

MMBTU / TON CLINKER = 3.94
LBS DRY FEED / MMBTU = 870
CO2 SCF / MMBTU = 2679
TOT SCF / MMBTU = 12378
NO LBS / SCF (3% O2) = 1.58 E-04
NO LBS / MMBTU = 2.28
NO LBS / TON CLINKER = 8.99

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVP GASTOUS EMISSIONS DATA (NO.O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.69**
N2 FLOW RATE (SCFH) - 143000 COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
809-813	.8	29.5	511	810	206	602	75	3.93	5.5
814-818	1.5	27.8	58	963	24	715	75	3.93	6.53
819-823	.4	30	478	727	189	540	75	3.93	4.93
824-828	.7	28.6	242	945	97	702	75	3.93	6.41
829-833	.8	29.1	118	970	48	727	78	3.78	6.38
834-838	.8	29	211	996	86	749	79	3.73	6.49
839-843	.6	29.9	564	889	227	668	79	3.73	5.79
850-853	1.2	28.3	51	1178	21	885	79	3.73	7.68
854-858	.9	28.6	52	1073	21	806	79	3.73	6.99
859-903	.4	29.2	699	659	279	495	79	3.73	4.29
904-908	.6	29.5	212	918	85	690	79	3.73	5.98
909-913	.6	29	312	1037	126	779	79	3.73	6.76
914-917	.9	29.3	123	1088	50	818	79	3.73	7.09
919-923	.9	29.2	352	1132	144	851	79	3.73	7.38
924-927	1	29.3	56	1109	23	834	79	3.73	7.23

STATISTICAL DATA

MEAN	.8	29.1	269	966	108	724	77.87	3.79	6.36
STD DEV	.29	.58	210.25	148.72	83.96	113.2	1.81	.09	.93
C195 MN	.16	.32	116.44	82.96	46.5	62.7	1	.05	.52
(N)	15	15	15	15	15	15	15	15	15

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 15.96
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 56.34

EMISSION FACTORS

MMBTU / TON CLINKER = 3.78
LBS DRY FEED / MMBTU = 907
CO2 SCF / MMBTU = 2794
TOT SCF / MMBTU = 12493
NO LBS / SCF (3% O2) = 1.15 E-04
NO LBS / MMBTU = 1.68
NO LBS / TON CLINKER = 6.37

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : FVD CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.69**
N2 FLOW RATE (SCFH) - 143000 COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
935-938	.3	30.2	990	770	393	579	79	3.73	5.02
939-942	.5	30	454	761	182	572	79	3.73	4.96
943-947	.4	30.2	496	682	198	513	79	3.73	4.44
948-952	.8	29.5	154	687	63	516	79	3.73	4.48
953-956	.1	30.4	1165	454	459	341	79	3.73	2.96
957-1000	.4	29.4	882	465	352	349	79	3.73	3.03
1001-1004	.3	29.9	645	579	256	435	79	3.73	3.77
1010-1013	.7	29.2	48	731	19	549	79	3.73	4.76
1014-1017	.3	29.3	525	633	209	476	79	3.73	4.12
1018-1021	.7	28.9	107	785	43	590	79	3.73	5.11
1022-1025	.4	29.7	600	690	240	519	79	3.73	4.5

STATISTICAL DATA

MEAN	.4	29.7	551	658	219	494	79	3.73	4.29
STD DEV	.21	.48	362.13	115.23	143.04	86.75	0	0	.75
CI95 MN	.14	.32	243.27	77.41	96.09	58.28	0	0	.5
(N)	11	11	11	11	11	11	11	11	11

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 16.2
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 57.16

EMISSION FACTORS

MMBTU / TON CLINKER = 3.73
LBS DRY FUEL / MMBTU = 920
CO2 SCF / MMBTU = 2834
TOT SCF / MMBTU = 12533
NO LBS / SCF (3% O2) = .79 E-04
NO LBS / MMBTU = 1.15
NO LBS / TON CLINKER = 4.29

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVD CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT
N2 FLOW RATE (SCFH) - 143000
COAL FLOW RATE (TON/HR) - 8.69**
COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1038	.1	29.3	813	583	320	438	79	3.73	3.8
1040	.1	29.1	147	634	58	477	79	3.73	4.13
1041	.3	29.3	984	596	391	448	79	3.73	3.88
1042	.2	29.7	575	608	227	457	79	3.73	3.96
1044	.2	29.5	301	623	119	468	79	3.73	4.06
1045	.5	28.8	48	652	19	490	79	3.73	4.25
1046	.6	29.8	430	648	173	487	79	3.73	4.22
1047	.6	28.9	44	676	18	508	79	3.73	4.4
1048	.6	28.1	44	702	18	528	79	3.73	4.57
1051	.1	29.3	752	558	296	419	79	3.73	3.64
1052	.3	29	101	645	40	485	79	3.73	4.2

STATISTICAL DATA

MEAN	.3	29.2	385	630	153	473	79	3.73	4.1
STD DEV	.21	.47	347.17	41.75	137.19	31.53	0	0	.27
C195 MN	.14	.32	233.22	28.04	92.16	21.18	0	0	.18
(N)	11	11	11	11	11	11	11	11	11

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 16.2
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 57.16

EMISSION FACTORS

MMBTU / TON CLINKER = 3.73
LBS DRY FUEL / MMBTU = 920
CO2 SCF / MMBTU = 2834
TOT SCF / MMBTU = 12533
NO LBS / SCF (3% O2) = .75 E-04
NO LBS / MMBTU = 1.1
NO LBS / TON CLINKER = 4.1

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.69**
N2 FLOW RATE (SCFH) - 196000 COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1053	.3	30	633	568	254	431	82	3.59	3.6
1054	.4	29	635	599	264	454	82	3.59	3.79
1055	.2	29.1	986	486	393	368	82	3.59	3.08
1056	.6	28.9	50	615	20	466	82	3.59	3.89
1057	.8	29.5	66	604	27	458	82	3.59	3.82
1059	.1	29.7	992	491	394	372	82	3.59	3.11
1100	.3	29.7	66	573	26	434	82	3.59	3.63
1102	.5	29.5	94	578	38	438	82	3.59	3.66
1103	.3	30.2	1010	511	405	387	82	3.59	3.24
1104	.1	29	1034	490	411	371	82	3.59	3.1
1105	.5	28.4	65	578	26	438	82	3.59	3.66
1106	.8	29.3	54	611	22	463	82	3.59	3.87
1107	.4	28.3	55	593	22	450	82	3.59	3.75

STATISTICAL DATA

MEAN	.4	29.3	443	561	177	425	82	3.59	3.55
STD DEV	.23	.57	442.84	48.79	176.57	37.14	0	0	.31
C195 MN	.14	.34	267.63	29.49	106.71	22.44	0	0	.19
(N)	13	13	13	13	13	13	13	13	13

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 16.81
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 59.33

EMISSION FACTORS

MMBTU / TON CLINKER = 3.59
LBS DRY FEED / MMBTU = 955
CO2 SCF / MMBTU = 2942
TOT SCF / MMBTU = 12641
NO LBS / SCF (3% O2) = .67 E-04
NO LBS / MMBTU = .99
NO LBS / TON CLINKER = 3.55

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.69**
N2 FLOW RATE (SCFH) - 196000 COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1117	.1	29.5	1760	180	699	136	82	3.59	1.14
1118	.1	30	1097	329	436	249	82	3.59	2.08
1119	.1	29.3	395	423	157	321	82	3.59	2.68
1120	.1	29.6	813	421	323	319	82	3.59	2.67
1121	.1	29.8	1666	214	661	162	82	3.59	1.35
1122	.1	28.6	194	403	77	305	82	3.59	2.55
1123	.2	29.2	147	424	59	321	82	3.59	2.68
1124	.1	30.1	924	401	367	304	82	3.59	2.54
1125	.1	29.1	1630	241	647	183	82	3.59	1.53
1126	.1	27.7	1930	30	766	23	82	3.59	.19
1127	.1	29.5	1671	169	663	128	82	3.59	1.07
1128	.1	29.8	1548	235	615	178	82	3.59	1.49
1129	.1	29.7	921	304	366	230	82	3.59	1.92
1130	.1	30.3	1814	107	720	81	82	3.59	.68
1131	.1	30.2	623	405	247	307	82	3.59	2.56

STATISTICAL DATA

MEAN	.1	29.5	1142	286	454	216	82	3.59	1.81
STD DEV	.03	.67	617.29	128.62	244.92	97.45	0	0	.81
C195 MN	.01	.37	341.88	71.23	135.65	53.97	0	0	.45
(N)	15	15	15	15	15	15	15	15	15

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 16.81
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 59.33

EMISSION FACTORS

MMBTU / TON CLINKER = 3.59
LBS DRY FEED / MMBTU = 955
CO2 SCF / MMBTU = 2942
TOT SCF / MMBTU = 12641
NO LBS / SCF (3% O2) = .34 E-04
NO LBS / MMBTU = .5
NO LBS / TON CLINKER = 1.81

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 11-17-83

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.69**
N2 FLOW RATE (SCFH) - 196000 COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1133	1.1	29.3	60	643	25	490	84	3.51	4
1134	1.1	29.8	43	657	18	501	84	3.51	4.08
1135	.1	30	39	628	16	479	84	3.51	3.9
1136	.5	31.3	1827	189	744	144	84	3.51	1.17
1137	.8	30.3	85	707	35	539	84	3.51	4.39
1138	.9	30.4	41	706	17	538	84	3.51	4.39
1139	.8	32.4	140	664	58	506	84	3.51	4.13
1140	.6	31.2	39	718	16	547	84	3.51	4.46
1141	.9	29.7	38	729	16	556	84	3.51	4.53
1142	1.3	30.8	33	732	14	558	84	3.51	4.55
1143	.1	29.8	35	694	15	529	84	3.51	4.31
1144	1.6	29.9	37	670	16	511	84	3.51	4.16
1145	.2	30	33	723	14	551	84	3.51	4.49
1146	.8	31.1	33	604	14	460	84	3.51	3.75
1147	.1	32.2	1758	223	702	170	84	3.51	1.39
1148	.2	32.3	216	560	87	427	84	3.51	3.48
1149	.3	31.3	305	559	123	426	84	3.51	3.47
1150	.3	32.3	1383	443	558	398	84	3.51	2.75
1151	.4	31.2	125	567	51	432	84	3.51	3.52
1152	.7	31.5	48	517	20	394	84	3.51	3.21
1153	.1	31.2	33	512	14	390	84	3.51	3.18
1154	.7	30.8	35	600	14	457	84	3.51	3.73
1155	.8	30.8	39	554	16	422	84	3.51	3.44
1156	.8	30.8	35	547	14	417	84	3.51	3.4
1157	.1	29	32	549	13	419	84	3.51	3.41
1158	.9	30.2	33	534	14	407	84	3.51	3.32
1159	.3	31	806	545	325	415	84	3.51	3.39
1200	.5	29.9	38	612	15	467	84	3.51	3.8
1201	.5	30.4	34	648	14	494	84	3.51	4.03

STATISTICAL DATA

MEAN	.8	30.7	255	587	103	448	84	3.51	3.65
STD DEV	.41	.94	511.05	130.52	206.02	99.5	0	0	.81
CI95 MN	.16	.36	194.35	49.64	78.35	37.84	0	0	.31
(N)	29	29	29	29	29	29	29	29	29

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 17.22
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 60.78

EMISSION FACTORS

MMBTU / TON CLINKER = 3.51
LBS DRY FEED / MMBTU = 979
CO2 SCF / MMBTU = 3014
TOT SCF / MMBTU = 12713
NO LBS / SCF (3% O2) = .7 E-04
NO LBS / MMBTU = 1.04
NO LBS / TON CLINKER = 3.65

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

DATE: 11/17/83

TIME		NO AS NO2* LBS/TON CLINKER	NO MG/J	NO PPM 3% O2	MAT. TEMP. (F)	KILN EXIT O2, %	KILN EXIT CO2, %	MILL OUTLET O2, %	KILN SPEED RPM	CO MG/J
(0636 - 0802)	MEAN	9	981	1320	2523	1.5	29.6	20.9	75	46
	STD. DEV.	1.9	219	290	48	.3	.8	0	2	50
	CI95	1.0	121	160	27	.2	.4	0	1	27
(0809 - 0927)	MEAN	6.4	724	966	2479	.8	29.1	15.7	78	110
	STD. DEV.	.9	113	149	22	.3	.6	.2	2	85
	CI95	.5	63	82	12	.2	.3	.1	1	47
(0935 - 1025)	MEAN	4.3	494	658	2426	.4	29.7	15.7	79	222
	STD. DEV.	.8	7	115	28	.2	.5	.3	0	145
	CI95	.5	58	77	19	.1	.3	.2	0	97
(1038 - 1052)	MEAN	4.1	473	630	2425	.3	29.2	15.1	79	154
	STD. DEV.	.3	32	42	9	.2	.5	.1	0	139
	CI95	.2	21	28	6	.1	.3	0	0	93
(1053 - 1107)	MEAN	3.6	425	561	2415	.4	29.3	14.4	82	179
	STD. DEV.	.3	37	49	0	.2	.6	.2	0	178
	CI95	.2	22	29	0	.1	.3	.1	0	108
(1117 - 1131)	MEAN	1.8	216	286	2366	.1	29.5	14.4	82	459
	STD. DEV.	.8	97	129	13.87	.03	.7	.45	0	248
	CI95	.5	54	71	7.68	.01	.4	.72	0	137
(1133 - 1201)	MEAN	3.7	448	587	2454	.8	30.7	21.0	84	105
	STD. DEV.	.8	100	131	18.18	.4	.9	0	0	208
	CI95	.3	38	50	6.91	.2	.4	0	0	79

*METHOD 2

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
1503	1	31.1	71	1425	29	1056	72	4.2	10.32
1504	1.2	31.5	74	1411	30	1046	72	4.2	10.22
1505	1.2	31.4	73	1465	30	1086	72	4.2	10.61
1506	1.7	30.3	64	1435	27	1064	72	4.2	10.39
1507	1.8	30	65	1502	27	1113	72	4.2	10.88
1508	1.4	31.9	74	1373	31	1018	72	4.2	9.94
1509	.3	32	1126	1079	441	800	72	4.2	7.81
1510	.2	32	300	1131	117	838	72	4.2	8.19
1511	.9	30.8	121	1325	49	982	72	4.2	9.59
1512	1.8	30.5	87	1652	37	1225	72	4.2	11.96
1513	1.8	29.9	72	1586	30	1176	72	4.2	11.43
1514	.7	31.7	138	1278	55	947	72	4.2	9.25
1515	.7	31.3	86	1333	24	988	72	4.2	9.65
1516	1.9	29.2	60	1645	25	1219	72	4.2	11.91
1517	1.1	31.7	71	1543	29	1144	72	4.2	11.17
1518	1.1	31	67	1555	27	1153	72	4.2	11.26
1519	.8	31.8	69	1378	28	1022	72	4.2	9.98
1520	1	30.8	67	1496	27	1109	72	4.2	10.83
1521	2.1	29.5	56	1648	24	1222	72	4.2	11.93
1522	2	30.6	62	1796	26	1331	72	4.2	13
1523	1.1	30.6	61	1569	25	1163	72	4.2	11.36
1524	1.4	29.2	67	1747	28	1295	72	4.2	12.65
1525	2	29.1	56	1827	24	1354	72	4.2	13.23
1526	1.2	31	66	1591	27	1179	72	4.2	11.52
1527	1.8	30.2	62	1753	26	1299	72	4.2	12.69
1528	1.2	30	65	1589	27	1178	72	4.2	11.51
1529	1.8	29.5	60	1811	25	1342	72	4.2	13.11
1530	1.5	30.2	63	1677	26	1243	72	4.2	12.14
1531	.5	32.8	155	1398	61	1036	72	4.2	10.12
1532	1.3	32.1	91	1646	37	1220	72	4.2	11.92

CONTINUED NEXT PAGE ...

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1533	.9	30.5	85	1610	34	1193	72	4.2	11.66
1534	1.7	29.6	72	1787	30	1325	72	4.2	12.94
1535	1.6	30.4	73	1816	31	1346	72	4.2	13.15
1536	1.8	31.2	72	1814	30	1345	72	4.2	13.13
1537	1.4	30.1	65	1793	27	1329	72	4.2	12.98
1538	1	30.9	71	1592	29	1180	72	4.2	11.53
1539	1.8	29.7	71	1839	30	1363	72	4.2	13.32
1540	1.6	30.4	62	1820	26	1349	72	4.2	13.18
1541	.5	33	1640	1161	649	861	72	4.2	8.41
1542	1.4	30.4	89	1777	37	1317	72	4.2	12.87
1543	1.6	29.4	70	1813	29	1344	72	4.2	13.13
1544	1	30.3	110	1676	45	1242	72	4.2	12.14
1545	1.6	29.5	76	1843	32	1366	72	4.2	13.34
1546	1.4	31.9	79	1611	33	1194	72	4.2	11.66
1547	2	28.9	60	1851	26	1372	72	4.2	13.4
1604	.9	33	70	1584	28	1174	72	4.2	11.47
1605	.5	33.9	125	1354	49	1004	72	4.2	9.8
1606	.3	33.2	212	1436	84	1065	72	4.2	10.4
1607	1.5	31.6	64	1766	27	1309	72	4.2	12.79
1608	1.9	30.4	51	1775	22	1316	72	4.2	12.85
1609	1.5	31.7	64	1598	27	1185	72	4.2	11.57
1610	2.1	30.8	51	1712	22	1269	72	4.2	12.4
1611	1.5	30.7	59	1540	25	1142	72	4.2	11.15
1612	1.8	30.3	53	1579	22	1171	72	4.2	11.43
1613	1.4	30.4	60	1413	25	1047	72	4.2	10.23
1614	.8	33.2	216	1238	87	918	72	4.2	8.96
1615	.9	31.7	78	1412	31	1047	72	4.2	10.22
1616	.8	33	694	1166	279	864	72	4.2	8.44
1617	.1	32.4	662	1162	257	861	72	4.2	8.41
1618	1.1	31.8	97	1440	40	1067	72	4.2	10.43

CONTINUED NEXT PAGE ...

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
1619	1.3	32.3	80	1473	33	1092	72	4.2	10.67
1620	1.1	31.4	73	1470	30	1090	72	4.2	10.64
1621	1.8	30.9	59	1368	25	1162	72	4.2	11.35
1622	2.5	29.1	46	1624	20	1204	72	4.2	11.76
1623	1.3	31.4	57	1410	23	1045	72	4.2	10.21
1624	1.3	32.8	53	1346	22	998	72	4.2	9.75
1625	1.8	29.3	45	1522	19	1128	72	4.2	11.02
1626	1.9	30.3	51	1451	22	1076	72	4.2	10.51
1627	1.3	31.6	55	1350	23	1001	72	4.2	9.77
1628	1.6	30.8	52	1452	22	1076	72	4.2	10.51
1629	1.2	33.3	54	1301	22	964	72	4.2	9.42
1630	1.5	30.9	49	1374	20	1019	72	4.2	9.95
1631	1.5	32.2	53	1381	22	1024	72	4.2	10
1632	2.2	29.7	50	1477	22	1095	72	4.2	10.69
1633	1.6	31.3	52	1351	22	1001	72	4.2	9.78
1634	1.3	31.8	54	1250	22	927	72	4.2	9.05
1635	1.6	30.1	47	1345	20	997	72	4.2	9.74
1636	.6	33.5	1597	868	635	643	72	4.2	6.28
1637	.5	31.6	267	1183	106	877	72	4.2	8.57
1638	1.6	30.9	61	1341	26	994	72	4.2	9.71
1639	1.9	29.9	53	1340	23	993	72	4.2	9.7
1640	.2	29.9	51	1349	22	1000	72	4.2	9.77
1641	1.5	30.8	47	1303	20	966	72	4.2	9.43
1642	1.8	30.4	43	1378	18	1022	72	4.2	9.98
1643	1.9	31.4	42	1307	18	969	72	4.2	9.46
1644	1.1	32.3	51	1146	21	850	72	4.2	8.3
1645	.7	31.4	94	1048	38	777	72	4.2	7.59
1646	1.1	32.3	54	1111	22	824	72	4.2	8.04
1647	1.3	30.2	45	1205	19	893	72	4.2	8.72
1648	2	30.9	44	1240	19	919	72	4.2	8.98

CONTINUED NEXT PAGE ...

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE
 N2 FLOW RATE (SCFH) - NONE
 COAL FLOW RATE (TON/HR) - 9.48**
 COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1649	1.6	29.3	42	1203	18	892	72	4.2	8.71
1650	1.6	29.3	42	1203	18	892	72	4.2	8.71
1651	1.6	29.3	42	1203	18	892	72	4.2	8.71
1652	1.6	29.3	42	1203	18	892	72	4.2	8.71
1653	1.6	29.3	42	1203	18	892	72	4.2	8.71
1654	1.6	29.3	42	1203	18	892	72	4.2	8.71
1655	1.6	29.3	42	1203	18	892	72	4.2	8.71
1656	1.6	31	53	1411	22	1046	72	4.2	10.22
1657	1.1	31.6	59	1266	24	938	72	4.2	9.17
1658	1.1	31.6	59	1286	24	953	72	4.2	9.31
1659	1.8	31.1	53	1369	22	1015	72	4.2	9.91
1700	.2	33.6	679	1921	265	1424	72	4.2	13.91

STATISTICAL DATA

MEAN	1.4	31	131	1464	53	1085	72	4.2	10.6
STD DEV	.49	1.2	259.77	225.32	102.41	166.98	0	0	1.63
CI95 MN	.1	.24	51.44	44.62	20.28	33.07	0	0	.32
(N)	102	102	102	102	102	102	102	102	102

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 14.76
 (CALCULATED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 52.09

EMISSION FACTORS

MMBTU / TON CLINKER = 4.2
 LBS DRY FUEL / MMBTU = 817
 CO2 SCF / MMBTU = 2516
 TOT SCF / MMBTU = 12362
 NO LBS / SCF (3% O2) = 1.75 E-04
 NO LBS / MMBTU = 2.52
 NO LBS / TON CLINKER = 10.6

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVIDENCE EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL MMV, FUEL FLOW RATE,
 KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1716	1	32.9	62	1113	25	827	73	4.14	7.97
1717	1.4	31.4	47	1257	20	934	73	4.14	9
1718	1.5	30.7	51	1282	21	953	73	4.14	9.18
1723	1.8	29.9	43	1257	18	934	73	4.14	9
1724	1.9	30.9	44	1210	19	900	73	4.14	8.66
1725	1.8	30.3	46	1199	19	891	73	4.14	8.59
1726	.1	33.5	2000	730	779	543	73	4.14	5.23
1727	.2	30	73	1276	31	949	73	4.14	9.14
1728	.9	32.2	71	1143	29	850	73	4.14	8.18
1729	.1	32.4	1389	892	541	663	73	4.14	6.39
1730	.2	28.9	61	1365	26	1015	73	4.14	9.77
1731	2.2	29.1	53	1380	24	1023	72	4.2	9.99
1732	1	30.5	59	1194	24	878	69	4.38	8.94
1733	2.9	29.1	47	1371	20	1008	69	4.38	10.27
1734	1.6	30.5	42	1273	17	936	69	4.38	9.54
1738	2.1	30	46	1447	20	1064	69	4.38	10.84
1739	2.4	28.9	44	1398	19	1028	69	4.38	10.47
1740	1.9	31.2	47	1251	19	920	69	4.38	9.37
1741	.2	33.9	536	960	207	706	69	4.38	7.19
1742	1.4	31.4	59	1363	24	1002	69	4.38	10.21
1743	1.7	31.5	50	1397	21	1027	69	4.38	10.47
1744	.9	31.3	54	1209	22	889	69	4.38	9.06
1745	1.2	31.7	42	1298	17	954	69	4.38	9.72
1746	1.5	30.9	42	1348	17	991	69	4.38	10.1
1747	1.3	31	49	1294	20	951	69	4.38	9.69
1748	1.4	31.3	43	1339	18	984	69	4.38	10.03
1749	1.9	30.2	39	1363	16	1002	69	4.38	10.21
1750	2.1	30.2	44	1340	19	985	69	4.38	10.04
1751	.8	31.8	149	1121	39	824	69	4.38	8.4
1752	1.2	31.8	47	1165	19	856	69	4.38	8.73

CONTINUED NEXT PAGE ...

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - BASELINE COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED / TON RPH CLINKER	MMBTU / TON CLINKER	NO LB / TON CLINKER
MEAN	1.4	31	179	1241	71	916	70.57	4.29	9.15
STD DEV	.62	1.26	429.17	158.47	166.75	115.54	1.96	.12	1.24
CI95 MN	.23	.47	160.24	59.17	62.26	43.14	.73	.04	.46
(N)	30	30	30	30	30	30	30	30	30

STATISTICAL DATA

MEAN	1.4	31	179	1241	71	916	70.57	4.29	9.15
STD DEV	.62	1.26	429.17	158.47	166.75	115.54	1.96	.12	1.24
CI95 MN	.23	.47	160.24	59.17	62.26	43.14	.73	.04	.46
(N)	30	30	30	30	30	30	30	30	30

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 14.47
 (CALCULATED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 51.06

EMISSION FACTORS

MMBTU / TON CLINKER = 4.28
 LBS DRY FEED / MMBTU = 801
 CO2 SCF / MMBTU = 2466
 TOT SCF / MMBTU = 12312
 NO LBS / SCF (3% O2) = 1.48 E-04
 NO LBS / MMBTU = 2.13
 NO LBS / TON CLINKER = 9.13

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVD CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT
N2 FLOW RATE (SCFH) - 201000

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE(BTU/LB) - 11589

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1901	1.4	29.8	48	1101	20	807	68	4.45	8.34
1902	1	31.5	47	1004	19	736	68	4.45	7.61
1903	.9	31.4	99	966	40	708	68	4.45	7.32
1904	.9	31.6	58	955	23	700	68	4.45	7.24
1905	1.1	30.5	45	989	18	725	68	4.45	7.5
1906	.5	31.1	78	959	31	703	68	4.45	7.27
1907	.4	30.7	60	882	23	646	68	4.45	6.69
1908	.6	30.1	65	941	26	690	68	4.45	7.13
1909	.8	30.1	51	988	20	724	68	4.45	7.49
1910	.9	31.7	53	941	21	690	68	4.45	7.13
1911	.3	31.9	589	832	228	610	68	4.45	6.31
1912	.9	29.6	49	1090	20	799	68	4.45	8.26
1913	.8	30.9	47	1057	19	775	68	4.45	8.01
1914	1.1	29.4	41	1093	17	801	68	4.45	8.28
1920	.4	31.9	213	894	83	655	68	4.45	6.78
1921	1	28.8	58	1003	23	735	68	4.45	7.6
1922	1.2	29.3	52	1083	21	794	68	4.45	8.21
1923	.9	30	50	1019	20	747	68	4.45	7.72
1924	1.4	29	42	1032	17	756	68	4.45	7.82
1925	1.1	30.6	41	952	17	698	68	4.45	7.22
1926	.8	31	47	924	19	677	68	4.45	7
1927	1	30	48	1046	20	767	68	4.45	7.93
1928	.7	30.9	322	956	127	701	68	4.45	7.25
1929	.6	29.3	117	984	46	721	68	4.45	7.46
1930	.7	29.2	52	1042	21	764	68	4.45	7.9
1931	1.1	28.4	46	1139	19	835	68	4.45	8.63
1932	1.3	27.8	37	1217	15	892	68	4.45	9.22
1933	1.6	29	42	1219	17	891	67	4.51	9.35
1934	1.7	28.4	43	1206	18	871	63	4.8	9.73
1935	1.6	28.7	42	1203	17	869	63	4.8	9.7

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SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - 201000 COAL HEAT VALUE(BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1936	1.3	30	37	1063	15	768	63	4.8	8.57
1937	.9	30.6	281	869	107	628	63	4.8	7.01
1938	1.2	30.3	70	1076	28	777	63	4.8	8.68
1939	1.2	30.2	55	1085	22	784	63	4.8	8.75
1940	1.1	29.2	50	1074	20	776	63	4.8	8.66
1941	1.1	29.6	43	1042	17	753	63	4.8	8.4
1942	.6	30.2	56	978	22	707	63	4.8	7.89
1943	.7	29.8	56	1044	22	754	63	4.8	8.42
1944	1.2	29.5	41	1086	16	785	63	4.8	8.76
1945	1.4	28.6	44	1136	18	821	63	4.8	9.16
1946	.1	28.9	41	1016	16	734	63	4.8	8.19
1947	.6	30	51	927	20	670	63	4.8	7.48
1948	1.4	28.9	43	1045	17	755	63	4.8	8.43
1958	.9	28.4	58	1106	23	799	63	4.8	8.92
1959	1.3	26.8	42	1248	17	902	63	4.8	10.06
2000	1.7	27.4	38	1255	16	907	63	4.8	10.12
2001	.3	28.3	697	989	266	714	63	4.8	7.98
2002	1.1	27.2	47	1220	18	881	63	4.8	9.84
2003	.7	28.4	51	1130	20	816	63	4.8	9.11
2004	.1	27.8	43	1139	17	823	63	4.8	9.19
2005	.1	29.5	555	881	210	636	63	4.8	7.1
2006	.8	28.1	73	1138	29	822	63	4.8	9.18
2007	.7	28.3	55	1097	21	793	63	4.8	8.85
2008	.9	28	50	1190	20	860	63	4.8	9.6
2009	.6	29.1	53	1096	21	792	63	4.8	8.84
2010	.8	27.9	55	1212	22	876	63	4.8	9.77
2011	1.2	28.1	44	1260	18	910	63	4.8	10.16
2012	.9	29.1	38	1181	15	853	63	4.8	9.52
2013	.2	30.3	1991	800	757	578	63	4.8	6.45
2014	.1	29.9	495	950	187	686	63	4.8	7.66

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SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT
N2 FLOW RATE (SCFH) - 201000

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2015	1	28	60	1283	24	927	63	4.8	10.35
2016	.9	28.9	57	1191	22	860	63	4.8	9.6
2017	.3	28.4	202	1072	77	774	63	4.8	8.64
2018	1.1	27.4	50	1311	20	947	63	4.8	10.57
2025	.9	28.6	41	1210	16	874	63	4.8	9.76
2026	.6	28.6	48	1125	19	813	63	4.8	9.07
2027	.1	30	1377	835	521	603	63	4.8	6.73
2028	1.1	27.7	49	1288	19	931	63	4.8	10.39
2029	1.3	27.5	42	1392	17	1006	63	4.8	11.23
2030	1.7	27.5	35	1384	14	1000	63	4.8	11.16
2031	.1	29.2	236	993	89	717	63	4.8	8.01
2032	.4	28.7	82	1060	31	766	63	4.8	8.55
2033	1.2	27.6	45	1314	18	949	63	4.8	10.6
2034	1.4	26.8	40	1396	16	1009	63	4.8	11.26
2035	.8	27.8	36	1284	14	928	63	4.8	10.35
2036	.2	28.5	600	1025	228	741	63	4.8	8.27
2037	.5	27.7	69	1288	27	931	63	4.8	10.39
2038	.7	28.1	45	1284	18	828	63	4.8	10.35
2039	1.4	26.3	41	1485	17	1073	63	4.8	11.98
2040	1.6	25.8	28	1476	11	1066	63	4.8	11.9
2041	.7	27.6	34	1262	13	912	63	4.8	10.18
2042	.1	28.3	1061	844	401	682	63	4.8	7.61
2043	.6	27.3	82	1298	32	838	63	4.8	10.47
2044	1.2	26.6	48	1487	19	1074	63	4.8	11.99
2045	1.5	26.1	46	1533	19	1108	63	4.8	12.36
2046	.8	27.7	46	1375	18	893	63	4.8	11.09
2047	.9	27.1	43	1443	17	1042	63	4.8	11.64
2048	1.2	26.7	39	1526	16	1102	63	4.8	12.31
2049	.2	29	1967	894	748	646	63	4.8	7.21
2050	.1	28.4	1505	956	569	691	63	4.8	7.71

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SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - 201000 COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J	NO NG/J	KILN SPEED / TON RPH CLINKER	MMBTU / TON CLINKER	NO LB / TON CLINKER
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STATISTICAL DATA

MEAN	.9	28.9	177	1116	88	810	64.54	4.69	8.85
STD DEV	.42	1.4	376.15	172.19	142.54	122.59	2.31	.16	1.49
CI95 MN	.09	.3	79.3	36.3	30.05	25.84	.49	.03	.31
(N)	90	90	90	90	90	90	90	90	90

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

EMISSION FACTORS

KILN FEEDER SPEED (RPM) - 13.23
 (CALCULATED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 46.7

MMBTU / TON CLINKER = 4.68
 LBS DRY FEED / MMBTU = 732
 CO2 SCF / MMBTU = 2255
 TOT SCF / MMBTU = 12101
 NO LBS / SCF (3% O2) = 1.33 E-04
 NO LBS / MMBTU = 1.88
 NO LBS / TON CLINKER = 8.82

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 8.91**
 N2 FLOW RATE (SCFH) - 201000 COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2104	1	27.3	35	1601	14	1170	63	4.51	12.28
2105	1.2	26.8	33	1655	13	1210	63	4.51	12.69
2106	1.3	28.6	119	1274	46	931	63	4.51	9.77
2107	1.1	27.2	31	1580	12	1155	63	4.51	12.12
2108	1.3	27	30	1659	12	1213	63	4.51	12.72
2109	2.1	26.4	28	1767	12	1291	63	4.51	13.55
2110	1.1	27.5	25	1594	10	1165	63	4.51	12.22
2111	1.5	28.1	323	1491	126	1090	63	4.51	11.43
2112	3.6	24	33	1696	15	1240	63	4.51	13.01
2113	3.9	23.5	29	1689	14	1234	63	4.51	12.95
2114	3.8	23.7	25	1634	12	1194	63	4.51	12.53
2115	3.4	24.1	23	1621	10	1185	63	4.51	12.43
2116	3.6	24	26	1559	12	1139	63	4.51	11.95
2117	3	24	23	1627	10	1189	63	4.51	12.48
2118	3.4	24.1	20	1563	9	1142	63	4.51	11.99
2119	3.4	24.7	27	1567	12	1145	63	4.51	12.02
2120	3.1	25.6	27	1584	12	1158	63	4.51	12.15
2125	2.8	25.5	23	1564	10	1143	63	4.51	11.99
2126	2.8	25.5	29	1542	13	1127	63	4.51	11.82
2127	2.7	26.2	21	1501	9	1097	63	4.51	11.51
2128	2.9	26.1	23	1525	10	1115	63	4.51	11.69
2129	2.8	25.2	28	1439	12	1052	63	4.51	11.03
2130	2.6	26.1	25	1476	11	1079	63	4.51	11.32
2131	2.8	25.7	26	1458	11	1066	63	4.51	11.18
2132	2.5	25.6	29	1437	13	1050	63	4.51	11.02
2133	2.5	25.8	22	1456	10	1064	63	4.51	11.16
2134	2.3	26.4	30	1411	13	1031	63	4.51	10.82
2135	2.5	26.2	26	1405	11	1027	63	4.51	10.77
2136	2.5	26	22	1354	10	990	63	4.51	10.38
2137	2.7	25.9	28	1302	12	952	63	4.51	9.98

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SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT
N2 FLOW RATE (SCFH) - 201000
COAL FLOW RATE (TON/HR) - 8.91**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2138	3.3	25.8	28	1234	13	902	63	4.51	9.46
2139	3.1	25.5	26	1223	12	894	63	4.51	9.38
2140	3.1	25.2	30	1223	13	894	63	4.51	9.38
2141	1.8	27.4	25	1156	10	845	63	4.51	8.86
2142	2.9	27.2	27	1140	12	833	63	4.51	8.74
2143	2.1	26.7	32	1142	14	835	63	4.51	8.76
2144	2.9	26.7	23	1137	10	831	63	4.51	8.72
2145	2.1	26.7	27	1152	11	842	63	4.51	8.83
2146	2.9	26.4	29	1113	12	813	63	4.51	8.53
2147	2.6	26.1	24	1083	10	782	63	4.51	8.3
2148	2.1	26.9	30	1128	13	824	63	4.51	8.65
2149	1.2	28.1	27	1053	11	770	63	4.51	8.07

STATISTICAL DATA

MEAN	2.4	26	36	1424	15	1041	63	4.51	10.92
STD DEV	.88	1.25	47.64	204.13	18.36	149.17	0	0	1.57
CI95 MN	.28	.39	14.86	63.66	5.73	46.52	0	0	.49
(N)	42	42	42	42	42	42	42	42	42

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.92
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 45.58

EMISSION FACTORS

MMBTU / TON CLINKER = 4.51
LBS DRY FEED / MMBTU = 760
CO2 SCF / MMBTU = 2342
TOT SCF / MMBTU = 12188
NO LBS / SCF (3% O2) = 1.7 E-04
NO LBS / MMBTU = 2.42
NO LBS / TON CLINKER = 10.92

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KUB CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT
N2 FLOW RATE (SCFH) - 234000

COAL FLOW RATE (TON/HR) - 9.1**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2158	1.7	27.5	40	908	17	661	63	4.61	7.08
2159	1.8	28	37	908	15	661	63	4.61	7.08
2200	1.4	28.7	34	869	14	633	63	4.61	6.78
2201	1.4	28.6	30	868	12	632	63	4.61	6.77
2202	.6	30.3	37	740	14	539	63	4.61	5.77
2203	.4	30.7	101	705	39	513	63	4.61	5.5
2204	.4	30.2	201	733	78	534	63	4.61	5.72
2205	.6	30.1	84	717	37	522	63	4.61	5.59
2206	1.5	28.4	52	845	21	615	63	4.61	6.59
2207	.7	29.5	56	739	22	538	63	4.61	5.76
2208	.9	28.1	37	777	15	566	63	4.61	6.06
2209	1.8	27.8	39	790	16	575	63	4.61	6.16
2210	1.7	27.6	37	854	15	622	63	4.61	6.66
2211	1.4	27.8	29	823	12	599	63	4.61	6.42
2212	.8	29.3	307	781	121	569	63	4.61	6.09
2213	1.2	28.4	35	822	14	598	63	4.61	6.41
2214	1.6	27.8	34	863	14	628	63	4.61	6.73
2215	1.5	28.2	27	865	11	630	63	4.61	6.75
2216	1.2	28	40	872	16	635	63	4.61	6.8
2217	1.5	28	28	826	11	674	63	4.61	7.22
2218	1.7	27.7	26	923	11	672	63	4.61	7.2
2219	1.6	27.3	30	910	12	662	63	4.61	7.1
2220	.7	28.6	29	856	11	623	63	4.61	6.68
2221	.6	29.9	67	828	26	603	63	4.61	6.46
2222	2.5	25.1	22	1044	9	753	60	4.84	8.47
2223	2.4	25.5	22	1065	9	768	60	4.84	8.64
2224	2.4	26.1	28	1029	12	742	60	4.84	8.35
2225	1.7	27.3	25	980	10	707	60	4.84	7.95
2226	1.9	26.2	29	1040	12	750	60	4.84	8.44
2227	2.8	26.4	21	1018	8	734	60	4.84	8.26

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SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - W2 INJECT
N2 FLOW RATE (SCFH) - 234000

COAL FLOW RATE (TON/HR) - 9.1**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
2232	1.6	27.2	29	993	12	716	60	4.84	8.06
2233	.9	28	27	801	11	578	60	4.84	6.5
2234	1.9	26.8	31	933	13	673	60	4.84	7.57
2235	2.2	25.8	24	956	10	690	60	4.84	7.76
2236	2.1	26	24	956	10	690	60	4.84	7.76
2237	1.6	27.2	30	861	12	621	60	4.84	6.99
2238	1.6	27	30	840	12	606	60	4.84	6.82
2239	1.7	26.3	21	864	9	623	60	4.84	7.01
2240	1.8	26.7	29	887	12	640	60	4.84	7.2

STATISTICAL DATA

MEAN	1.5	27.8	47	877	19	636	61.85	4.7	6.85
STD DEV	.57	1.36	53.1	94.46	20.7	66.57	1.48	.11	.85
CI95 MN	.19	.44	17.22	30.63	6.71	21.59	.48	.04	.27
(N)	39	39	39	39	39	39	39	39	39

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.68
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 44.75

EMISSION FACTORS

MMBTU / TON CLINKER = 4.69
LBS DRY FUEL / MMBTU = 731
CO2 SCF / MMBTU = 2251
TOT SCF / MMBTU = 12097
NO LBS / SCF (3% O2) = 1.05 E-04
NO LBS / MMBTU = 1.48
NO LBS / TON CLINKER = 6.94

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 9.29**
 N2 FLOW RATE (SCFH) - 250000 COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
2241	1.6	27.2	32	935	13	672	60	4.94	7.72
2242	2.3	25.9	24	855	10	615	60	4.94	7.06
2243	2.2	26.8	29	880	12	632	60	4.94	7.26
2244	1.5	27.2	23	844	9	607	60	4.94	6.97
2245	1.6	27	28	831	11	597	60	4.94	6.86
2246	1.1	27.6	29	774	11	556	60	4.94	6.39
2247	1.7	26.1	27	842	11	605	60	4.94	6.95
2248	1.4	26.9	31	804	12	578	60	4.94	6.64
2249	1.4	26.9	25	866	10	622	60	4.94	7.15
2250	.9	28.9	2000	514	760	369	60	4.94	4.24
2251	.9	28	35	770	22	553	60	4.94	6.36
2252	1.5	26.6	38	855	16	615	60	4.94	7.06
2253	1.9	26	33	963	14	632	60	4.94	7.95
2254	1.7	26.2	34	854	14	614	60	4.94	7.05
2255	.8	27.8	154	760	60	546	60	4.94	6.27
2256	.7	27.9	36	757	14	544	60	4.94	6.25
2257	.2	28	1435	626	543	450	60	4.94	5.17
2258	.2	25	41	888	17	638	60	4.94	7.33
2259	2	26	36	891	15	640	60	4.94	7.36

STATISTICAL DATA

MEAN	1.4	26.9	216	816	83	587	60	4.94	6.74
STD DEV	.6	.85	538.07	104.69	203.93	75.3	0	0	.86
C195 MN	.29	.46	259.35	50.46	98.3	36.29	0	0	.42
(N)	19	19	19	19	19	19	19	19	19

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.3
 (CALCULATED AVERAGE)
 FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 43.41

EMISSION FACTORS

MMBTU / TON CLINKER = 4.94
 LBS DRY FEED / MMBTU = 895
 CO2 SCF / MMBTU = 2139
 TOT SCF / MMBTU = 11985
 NO LBS / SCF (3% O2) = .97 E-04
 NO LBS / MMBTU = 1.36
 NO LBS / TON CLINKER = 6.74

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2: FUP CARBON EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - W2 INJECT COAL FLOW RATE (TON/HR) - 9.48**
 N2 FLOW RATE (SCFH) - REDUCING COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2305	1.9	26.1	29	907	12	651	61	4.96	7.51
2306	1.7	27	25	896	10	644	61	4.96	7.42
2307	1.4	27.3	36	859	14	617	61	4.96	7.11
2308	1.4	27.3	29	898	12	645	61	4.96	7.43
2309	2	25.5	26	1002	11	720	61	4.96	8.3
2310	2	26.3	23	1024	10	736	61	4.96	8.48
2311	1.7	26.6	23	983	9	706	61	4.96	8.14
2312	1.8	27.2	24	974	10	700	61	4.96	8.06
2313	1.5	27.7	31	950	12	682	61	4.96	7.87
2314	1.6	28.3	31	989	13	710	61	4.96	8.19
2315	2	27.3	24	1038	10	746	61	4.96	8.59
2316	2.3	26.8	24	1079	10	775	61	4.96	8.93
2317	2.3	26.8	25	1071	11	769	61	4.96	8.87
2318	1.8	28.2	23	1033	9	742	61	4.96	8.55
2319	1.7	28.5	312	859	121	617	61	4.96	7.11
2320	1.8	27.1	25	1006	10	727	63	4.8	8.11
2321	2.4	26.1	25	1171	11	846	63	4.8	9.44
2322	2.3	26.3	28	1088	12	786	63	4.8	8.77
2323	2.8	25.7	29	1204	13	870	63	4.8	9.71
2324	2.2	26.2	24	1110	10	802	63	4.8	8.95
2325	2.3	26.1	21	1104	9	798	63	4.8	8.9
2326	2.2	25.4	27	1189	12	859	63	4.8	9.59
2327	2.9	26.1	23	1109	10	801	63	4.8	8.94
2328	1.9	28.6	24	1118	10	808	63	4.8	9.02
2336	1.8	28.7	31	1155	13	849	69	4.38	8.65
2337	2.6	28.4	30	1197	13	880	69	4.38	8.97
2338	2.3	27.9	24	1153	10	847	69	4.38	8.64
2339	1.9	28.7	22	1140	9	838	69	4.38	8.54
2340	2.5	28.6	30	1218	13	895	69	4.38	9.12
2341	2.3	27.8	23	1214	10	892	69	4.38	9.09

CONTINUED NEXT PAGE ...

SITE 4 ROTARY KILN

DATE - 4-17-84

TEST CONDITION - N2 INJECT COAL FLOW RATE (TON/HR) - 9.48**
N2 FLOW RATE (SCFH) - REDUCING COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
2342	1.3	29.2	26	1076	11	791	69	4.38	8.06
2343	1.3	29.6	31	1109	13	817	70	4.32	8.21
2344	2.8	28.1	29	1244	13	917	70	4.32	9.21
2345	2.9	28.6	30	1211	18	893	70	4.32	8.97
2346	2.4	27.7	23	1213	10	894	70	4.32	8.98
2347	2.6	28.2	25	1199	11	884	70	4.32	8.88
2348	1.5	29.7	29	1109	12	824	73	4.14	7.94
2349	2.1	28.9	27	1212	12	901	73	4.14	8.68
2350	3	27.9	24	1165	11	866	73	4.14	8.34
2351	2.2	27.8	21	1184	9	880	73	4.14	8.48
2352	2.3	29.1	30	1110	13	825	73	4.14	7.95
2353	1.8	29.3	24	1043	10	775	73	4.14	7.47
2354	1.9	28.9	30	1036	13	770	73	4.14	7.42

STATISTICAL DATA

MEAN	2.1	27.6	33	1085	14	791	65.72	4.62	8.46
STD DEV	.51	1.18	43.69	106.91	16.81	84.69	4.73	.33	.66
CI95 MN	.16	.36	13.46	32.95	5.18	26.1	1.46	.1	.2
(N)	43	43	43	43	43	43	43	43	43

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION	EMISSION FACTORS
KILN FEEDER SPEED (RPM) - 13.47 (CALCULATED AVERAGE)	MMBTU / TON CLINKER = 4.6
FEEDER REVS/TON CLINKER - 17	LBS DRY FUEL / MMBTU = 746
CLINKER RATE (TON/HR) - 47.55	CO2 SCF / MMBTU = 2296
	TOT SCF / MMBTU = 12142
	NO LBS / SCF (3% O2) = 1.3 E-04
	NO LBS / MMBTU = 1.84
	NO LBS / TON CLINKER = 8.45

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : FUD GASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL MNV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 4-18-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPM	MMBTU / TON CLINKER	NO LB / TON CLINKER
8	1.4	32	33	996	13	720	63	4.8	8.03
9	2.2	30.1	25	1123	11	811	63	4.8	9.06
10	2.3	30.9	30	1129	13	813	62	4.88	9.22
11	2.3	30.1	32	1099	13	792	62	4.88	8.98
12	1.6	30.4	30	955	20	688	62	4.88	7.8
13	1.8	31.4	27	994	11	716	62	4.88	8.12
14	2	30.1	25	987	10	711	62	4.88	8.06
15	3.1	28.6	25	981	11	707	62	4.88	8.01
16	2.3	29	31	918	13	661	62	4.88	7.5
17	2.7	28.7	28	969	12	698	62	4.88	7.92
18	2.1	29.6	27	898	11	647	62	4.88	7.34
19	1.9	28.9	23	823	9	665	62	4.88	7.54
20	3.3	28.1	24	1015	11	731	62	4.88	8.29
21	2.9	28.9	24	995	10	717	62	4.88	8.13
22	1.7	31.3	27	900	11	648	62	4.88	7.35
23	2.6	30.4	27	1023	12	737	62	4.88	8.36
24	2.7	28.8	29	1051	12	757	62	4.88	8.59
25	2.7	29.6	26	1031	11	743	62	4.88	8.42
26	3.8	28.8	27	1062	12	765	62	4.88	8.68
27	3.2	28.8	22	943	10	679	62	4.88	7.7
28	2.9	29.3	26	985	11	710	62	4.88	8.05
29	1.6	32.8	35	862	14	621	62	4.88	7.04
30	2.6	30.2	33	925	14	666	62	4.88	7.56
38	1.2	30.7	32	841	13	606	62	4.88	6.87
39	2.8	28.4	24	987	10	709	61	4.96	8.17
40	2.7	29	26	965	11	683	56	5.4	8.58
41	1.8	29	25	921	10	650	55	5.5	8.31
42	2.8	28.2	25	936	11	659	54	5.6	8.58
43	3.3	26.8	23	1025	10	723	55	5.5	9.25
44	2.6	28.5	25	838	10	662	55	5.5	8.46

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SITE 4 ROTARY KILN

DATE - 4-18-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE

COAL FLOW RATE (TON/HR) - 9.48**
COAL HEAT VALUE (BTU/LB) - 11539

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
45	2.1	29.2	32	883	13	623	55	5.5	7.97
46	1.8	29.4	26	859	10	606	55	5.5	7.75
47	2.5	29.2	29	907	12	640	55	5.5	8.18
48	2.5	29.1	23	890	10	628	55	5.5	8.03
49	3.1	28	23	953	10	673	55	5.5	8.6
50	2.7	28.4	25	941	11	664	55	5.5	8.49
51	2.5	28.9	28	916	12	646	55	5.5	8.27
52	2.8	28.3	30	932	13	658	55	5.5	8.41
53	2.3	29.4	29	987	12	697	55	5.5	8.91
54	2.9	28.3	28	945	12	667	55	5.5	8.53

STATISTICAL DATA

MEAN	2.4	29.4	28	985	12	690	59.4	5.11	8.18
STD DEV	.53	1.2	4.85	68.16	1.85	51.97	3.47	.31	.56
CI95 MW	.17	.38	1.53	21.8	.59	16.62	1.11	.1	.18
(N)	40	40	40	40	40	40	40	40	40

AVERAGE CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

CLINKER RATE CALCULATION

KILN FEEDER SPEED (RPM) - 12.18
(CALCULATED AVERAGE)
FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 42.98

EMISSION FACTORS

MMBTU / TON CLINKER = 5.09
LBS DRY FEED / MMBTU = 674
CO2 SCF / MMBTU = 2076
TOT SCF / MMBTU = 11922
NO LBS / SCF (3% O2) = 1.15 E-04
NO LBS / MMBTU = 1.6
NO LBS / TON CLINKER = 8.17

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL MW, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

APPENDIX G-1

LOW EXCESS AIR TEST SERIES

S I T E 4
EPA 806038. CLINKER SAMPLES

SAMPLE #	DATE 1984	TIME	SAMPLE LOCATION	KILN CONDITION	KVR % FREE CAO	COMMENTS
C-132	2/24	1715	WEIGH BELT	AS FOUND	-	
C-133	2/24	1730	WEIGH BELT	AS FOUND	-	
C-134	2/24	1745	WEIGH BELT	AS FOUND	-	
C-135	2/24	1800	WEIGH BELT	AS FOUND	-	
C-136	2/24	1815	WEIGH BELT	AS FOUND	-	
C-137	2/24	1830	WEIGH BELT	AS FOUND	-	
C-138	2/24	1845	WEIGH BELT	AS FOUND	-	
C-139	2/24	1905	WEIGH BELT	AS FOUND	-	
C-140	2/24	1915	WEIGH BELT	AS FOUND	-	
C-141	2/24	1930	WEIGH BELT	AS FOUND	-	
C-142	2/24	1945	WEIGH BELT	AS FOUND	-	
C-143	2/24	2000	WEIGH BELT	AS FOUND	-	
C-144	2/24	2015	WEIGH BELT	AS FOUND	-	
C-145	2/24	2030	WEIGH BELT	AS FOUND	-	
C-146	2/29	1230	WEIGH BELT	AS FOUND	.28/.28	
C-147	2/29	1330	WEIGH BELT	AS FOUND	.35/.35	
C-148	2/29	1430	WEIGH BELT	AS FOUND	.10/.10	
C-149	2/29	1530	WEIGH BELT	AS FOUND	.13/.13	
C-150	2/29	1635	WEIGH BELT	AS FOUND	.51/.51	
C-151	2/29	1730	WEIGH BELT	AS FOUND	.51/.51	
C-152	3/1	1907	WEIGH BELT	AS FOUND	.99	
C-153	3/1	2008	WEIGH BELT	AS FOUND	-	
C-154	3/1	2110	WEIGH BELT	AS FOUND	1.03/1.03	
C-155	3/1	2200	WEIGH BELT	AS FOUND	.13/.13	
C-156	3/1	2300	WEIGH BELT	AS FOUND	.40	
C-157	3/2	0005	WEIGH BELT	AS FOUND	.39	
C-158	3/2	0105	WEIGH BELT	AS FOUND	.14	
C-159	3/2	0210	WEIGH BELT	AS FOUND	.18	
C-160	3/2	0310	WEIGH BELT	AS FOUND	.67	
C-161	3/2	0410	WEIGH BELT	AS FOUND	.21	
C-162	3/2	0510	WEIGH BELT	AS FOUND	.14	
C-163	3/2	0610	WEIGH BELT	AS FOUND	-	
C-164	3/3	1908	WEIGH BELT	AS FOUND	.19/.19	
C-165	3/3	2006	WEIGH BELT	AS FOUND	.19/.19	

APPENDIX G-2

STRIP CHARTS OF KILN EMISSIONS AND OPERATIONS DATA FROM
HOST SITE CONTROL ROOM

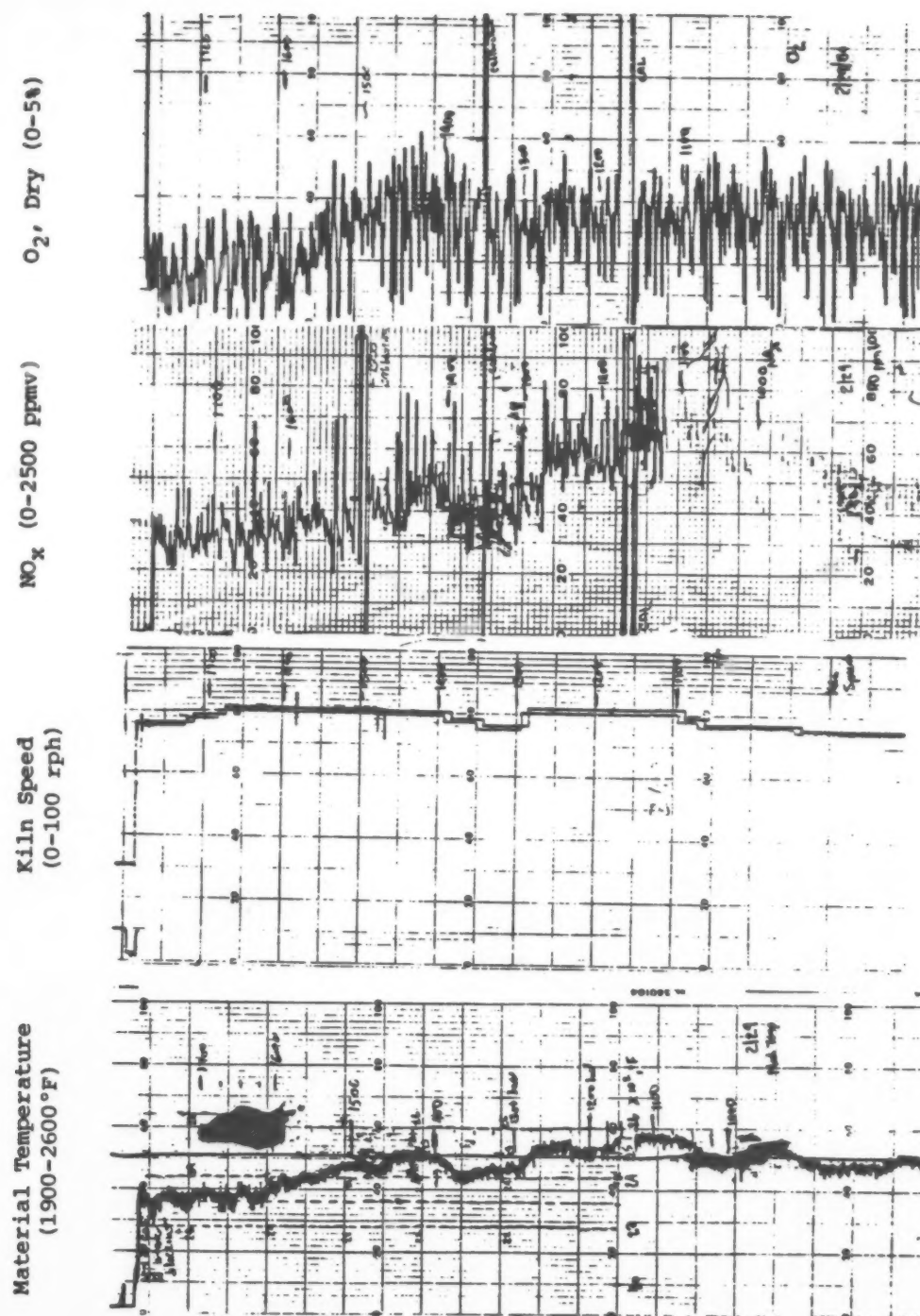


Figure G-1. February 29 (Mat. Temp., Kiln Speed, NO_x, O₂); 0730 - 1800 hrs

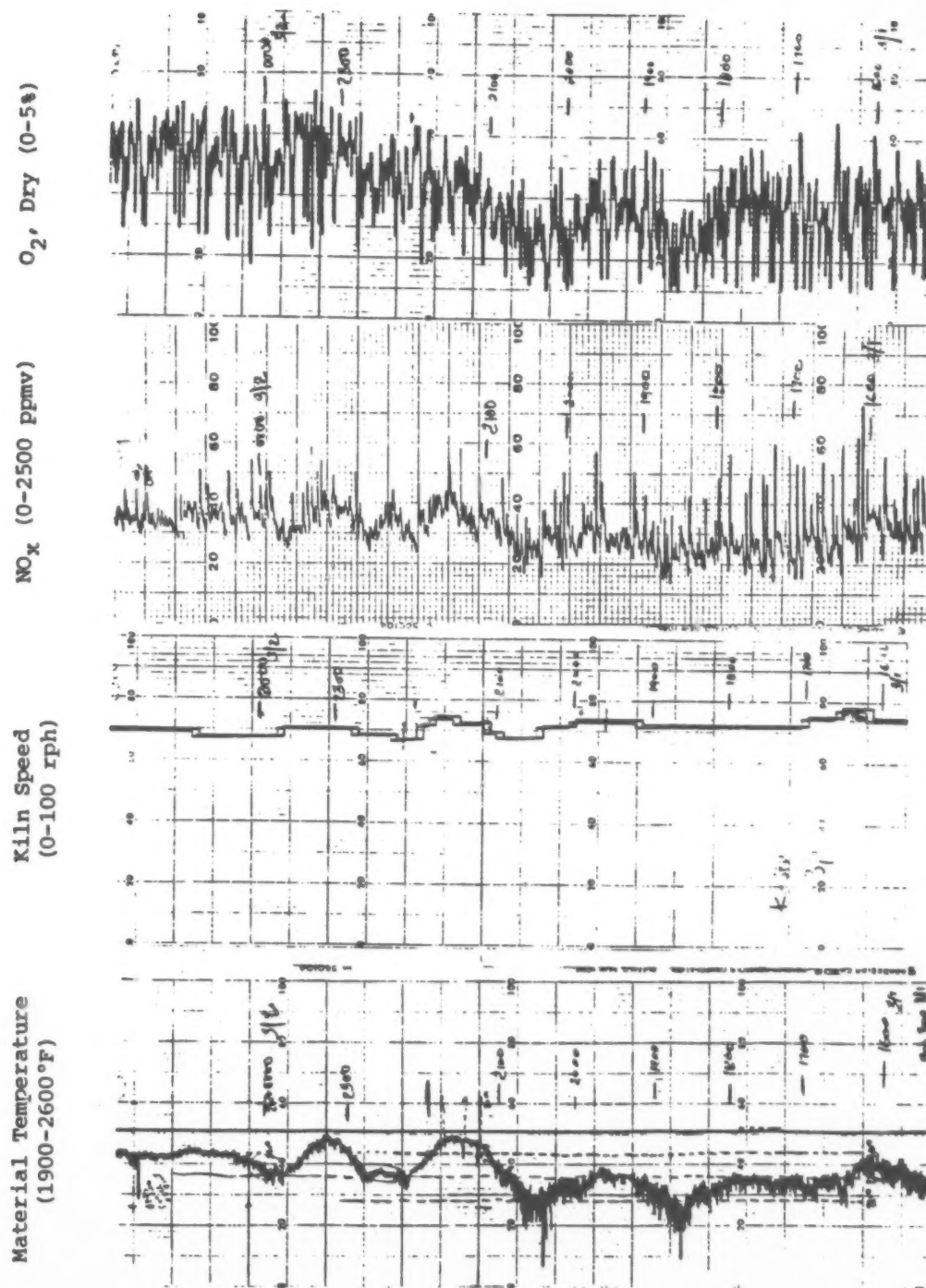


Figure G-2. March 1, 2 (Mat. Temp., Kiln Speed, NO_x, O₂); 1500 - 0200 hrs

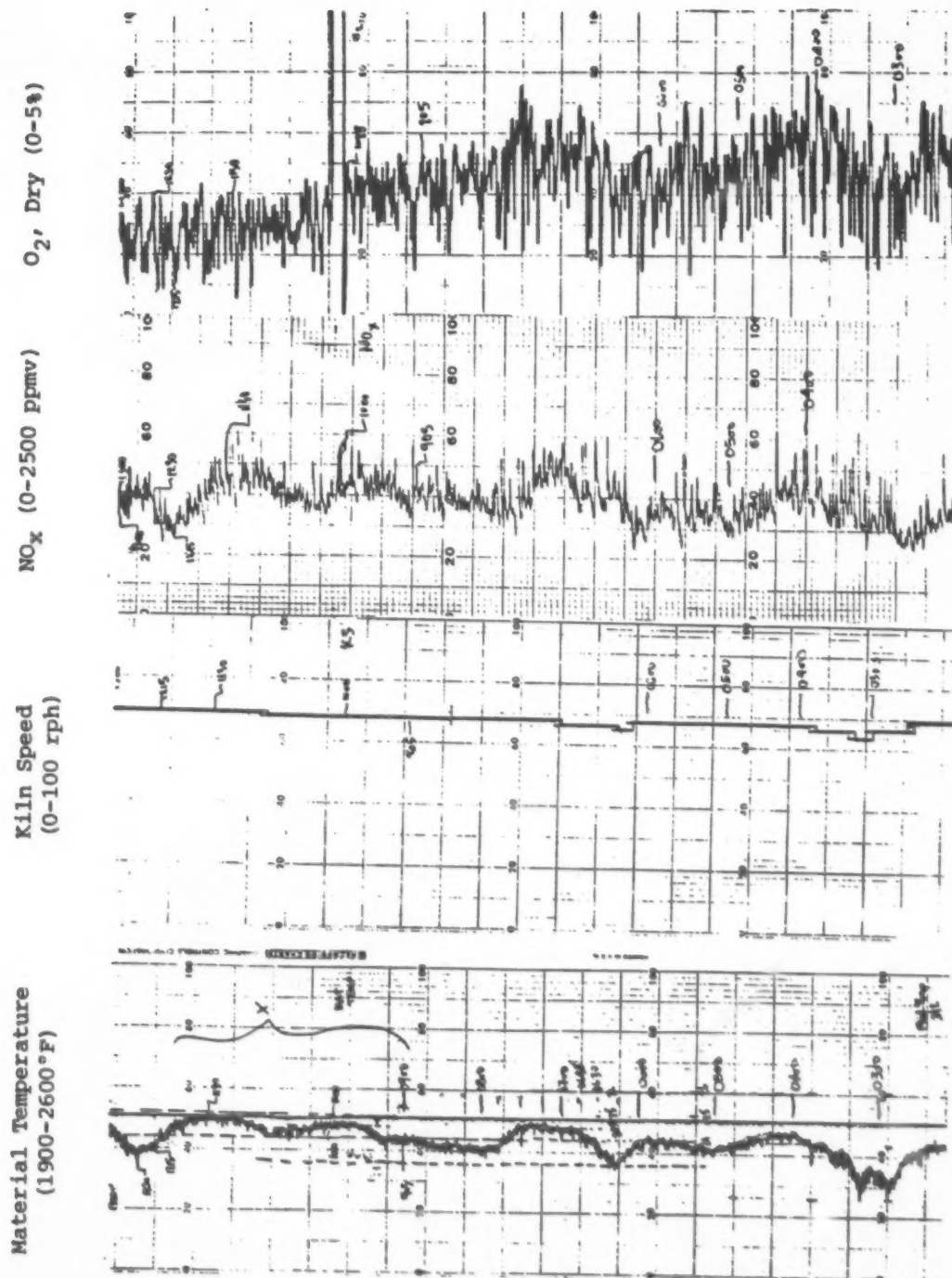


Figure G-3. March 2 (Mat. Temp., Kiln Speed, NO_x, O₂); 0200 - 1300 hrs

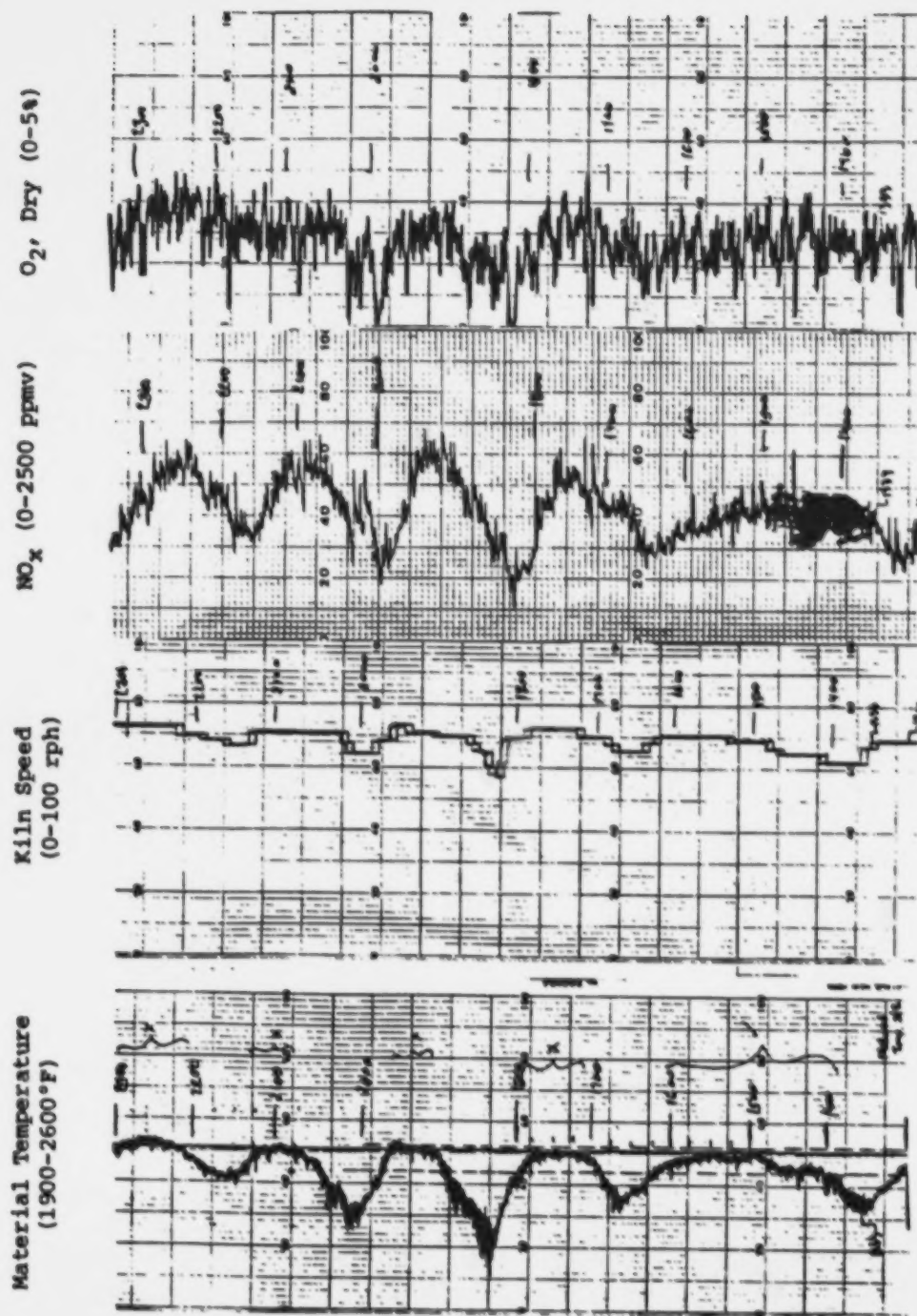


Figure G-4. March 2 (Mat. Temp., Kiln Speed, NO_x, O₂); 1300 - 2300 hrs

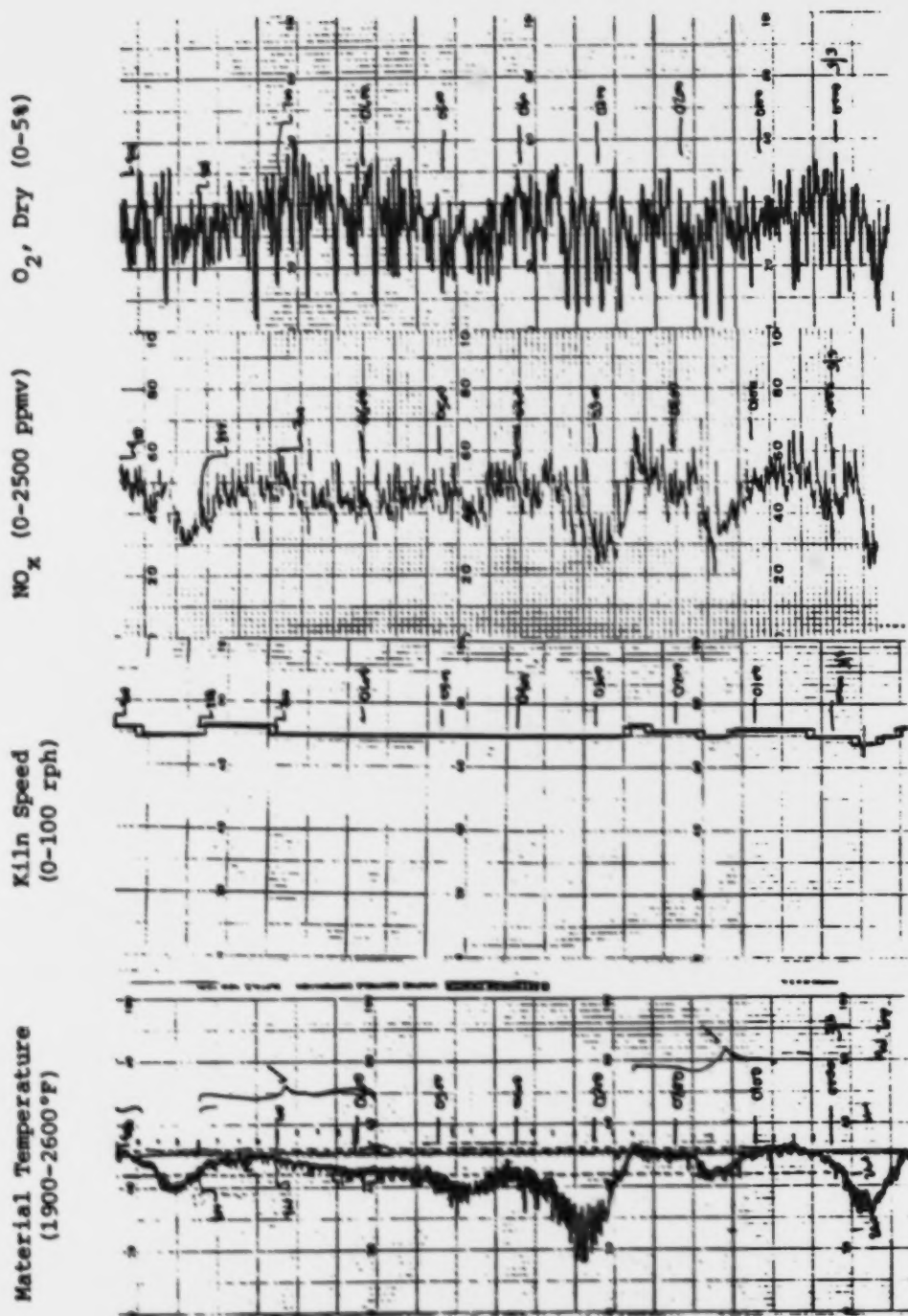


Figure G-5. March 2, 3 (Mat. Temp., Kiln Speed, NO_x, O₂); 2300 - 0900 hrs

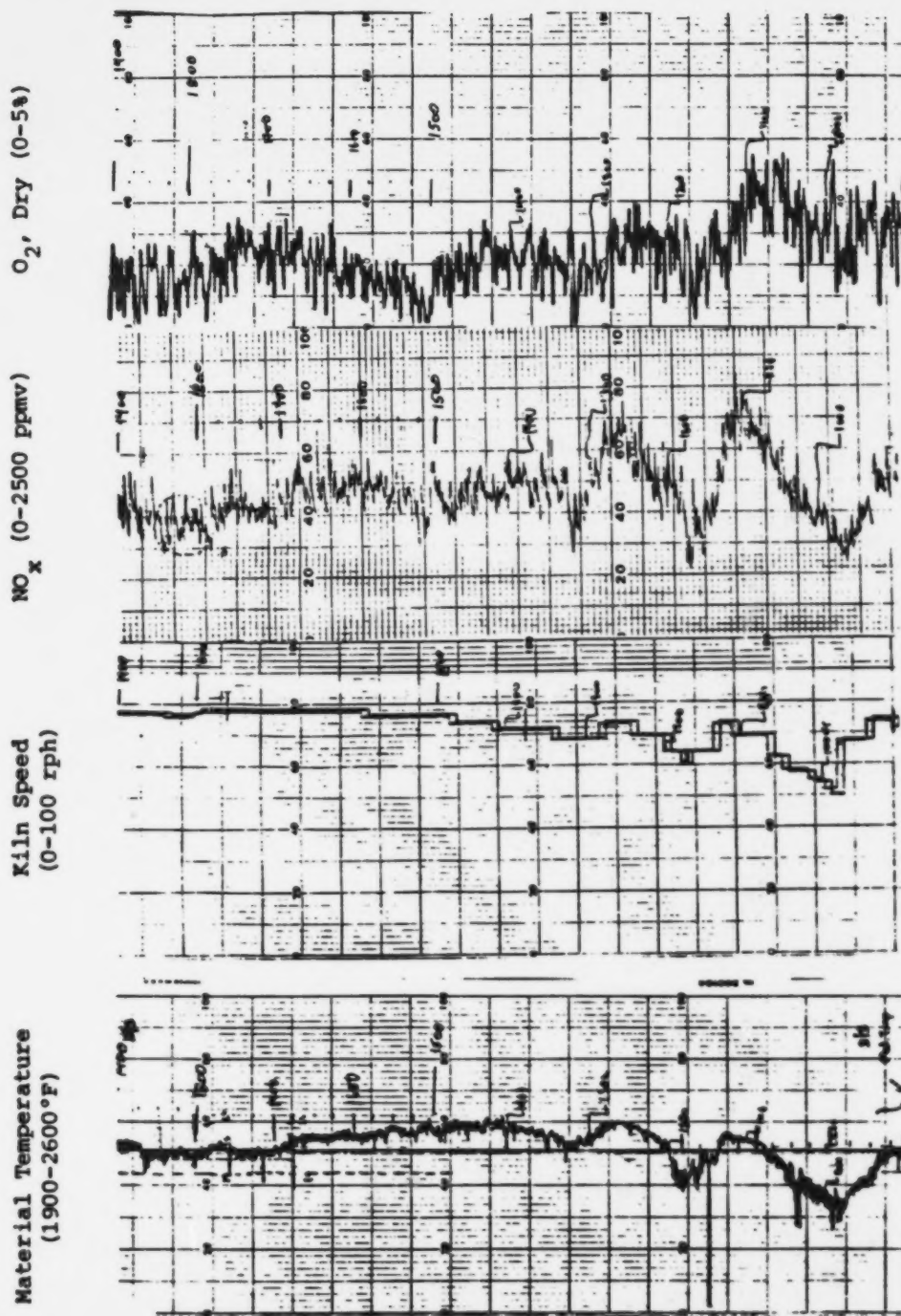


Figure G-6. March 3 (Mat. Temp., Kiln Speed, NO_x, O₂); 0900 - 1900 hrs

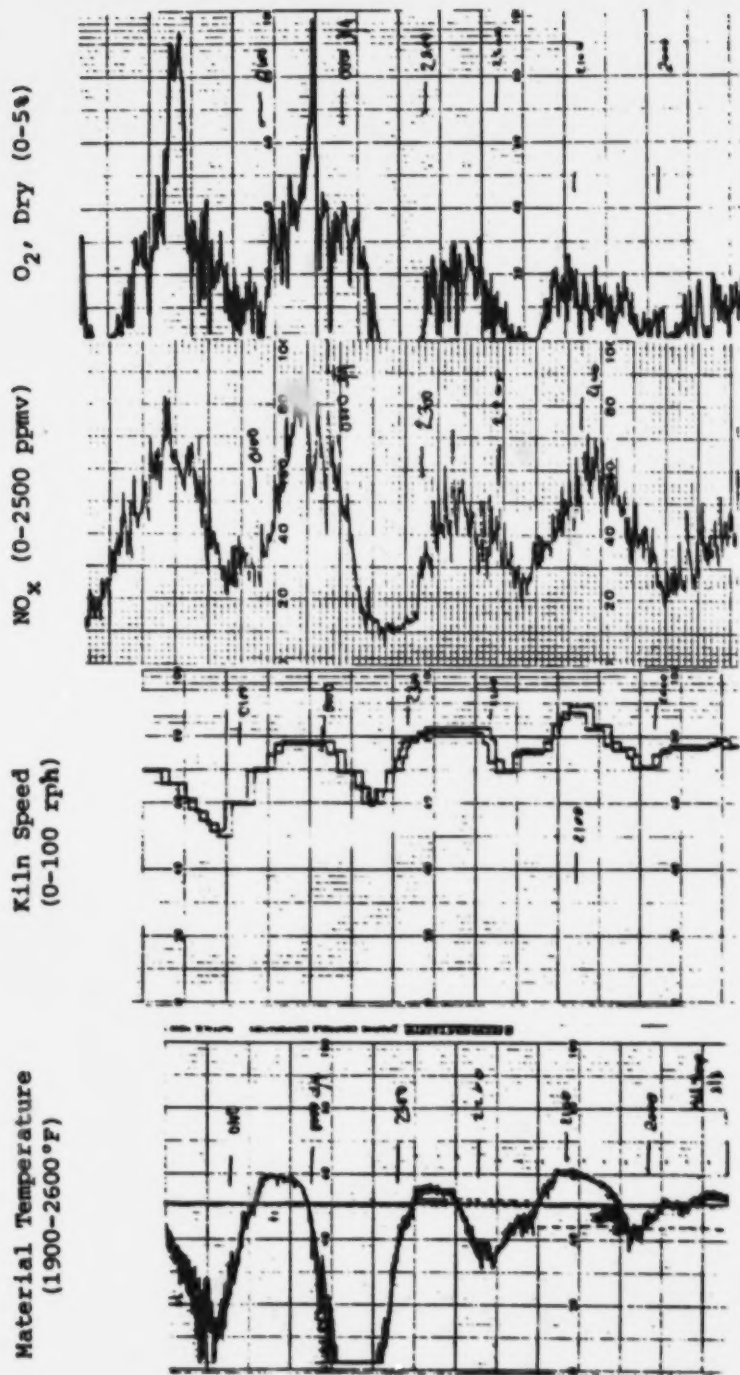


Figure G-7. March 3 (Mat. Temp., Kiln Speed, NO_x, O₂); 1900 - 0130 hrs

APPENDIX G-3

EMISSIONS DATA

SITE 4 ROTARY KILN

DATE - 2-29-84

TEST CONDITION - BASELINE COAL FLOW RATE (TON/HR) - 9.08**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO NG/J --	NO NG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1152-1207	1.7	30.1	32	1315.1	14	984	81	3.8	8.7
1212-1225	1.9	29.6	30	1354.1	13	1013	81	3.8	8.95
1226-1240	2	29.5	39	1315.7	17	985	81	3.8	8.7
1241-1255	1.8	31	197	1085.6	84	812	81	3.8	7.18
1256-1311	1.8	30.4	188	973.5	79	717	75	4.1	6.84
1318-1331	1.8	30.3	79	901.3	33	663	75	4.1	6.39
1332-1346	2	29.6	67	902.4	29	668	77	4	6.21
1347-1401	2.1	28.9	200	1008.5	86	751	79	3.9	6.8
1402-1416	2.2	28.9	42	1082.5	18	806	79	3.9	7.3
1417-1440	2.2	29.6	284	997.1	123	742	79	3.9	6.72

STATISTICAL DATA

MEAN	2	29.8	116	1094	50	814	78.8	3.91	7.37
STD DEV	.18	.68	92.29	173.51	39.62	133.54	2.39	.12	1.03
CI95 MN	.13	.49	66.01	124.11	28.34	95.52	1.71	.09	.74
(N)	10	10	10	10	10	10	10	10	10

MEASURED CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

MEASURED CLINKER RATE

FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 55.44

EMISSION FACTORS

MMBTU / TON CLINKER = 4.02
 LBS DRY FEED / MMBTU = 854
 CO2 SCF / MMBTU = 2631
 TOT SCF / MMBTU = 12330
 NO LBS / SCF (3% O2) = 1.31 E-04
 NO LBS / MMBTU = 1.88
 NO LBS / TON CLINKER = 7.55

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVB CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
 KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 3-1-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE
COAL FLOW RATE (TON/HR) - 8.83**
COAL HEAT VALUE(BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
2114-2128	1.9	27.7	111	880	47	646	72	4.16	6.24
2129-2147	1.8	28.8	52	899	22	662	73	4.1	6.31

STATISTICAL DATA

MEAN	1.9	28.3	82	890	35	654	72.5	4.13	6.28
STD DEV	.07	.78	41.72	13.44	17.68	11.31	.71	.04	.05
CI95 MN	.64	6.99	374.83	120.71	158.83	101.65	6.35	.38	.44
(N)	2	2	2	2	2	2	2	2	2

MEASURED CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

MEASURED CLINKER RATE

FEEDER REVS/TON CLINKER - 17
CLINKER RATE (TON/HR) - 42.5

EMISSION FACTORS

MMBTU / TON CLINKER = 5.09
LBS DRY FEED / MMBTU = 673
CO2 SCF / MMBTU = 2074
TOT SCF / MMBTU = 11773
NO LBS / SCF (3% O2) = 1.06 E-04
NO LBS / MMBTU = 1.46
NO LBS / TON CLINKER = 7.44

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : KVP CASEOUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE,
KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 3-2-84

TEST CONDITION - LOW % O2 COAL FLOW RATE (TON/HR) - 9.06**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1533-1547	1.3	29.9	30	885.7	12	641	69	4.45	6.64
1548-1602	1.4	29.9	30	860.7	12	625	70	4.39	6.37

STATISTICAL DATA

MEAN	1.4	29.9	30	873	12	633	69.5	4.42	6.51
STD DEV	.07	0	0	17.68	0	11.31	.71	.04	.19
C195 MN	.64	0	0	158.83	0	101.65	6.35	.38	1.72
(N)	2	2	2	2	2	2	2	2	2

MEASURED CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

MEASURED CLINKER RATE

EMISSION FACTORS

FEEDER REVS/TON CLINKER - 17
 CLINKER RATE (TON/HR) - 43.6

MMBTU / TON CLINKER = 5.1
 LBS DRY FEED / MMBTU = 673
 CO2 SCF / MMBTU = 2074
 TOT SCF / MMBTU = 11773
 NO LBS / SCF (3% O2) = 1.04 E-04
 NO LBS / MMBTU = 1.43
 NO LBS / TON CLINKER = 7.3

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVD CASEDUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL MW, FUEL FLOW RATE,
 KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 3-3-84

TEST CONDITION - BASELINE
N2 FLOW RATE (SCFH) - NONE

COAL FLOW RATE (TON/HR) - 9.13**
COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
0046-0100	1.8	29.7	28	1099	12	801	72	4.3	8.01
0101-0115	1.7	30.1	69	996.3	29	726	72	4.3	7.26
0116-0130	1.6	30.3	205	815.9	84	592	70	4.42	6.08
0131-0145	1.5	29.7	164	988.3	67	716	70	4.42	7.36
0218-0232	1.6	29.9	38	1230.5	16	900	73	4.24	8.87
0606-0620	1.8	29.2	33	1000.3	14	725	70	4.42	7.45
0621-0635	2.0	28.3	27	1012.	11	734	70	4.42	7.54
0636-0658	2.0	28.5	59	1078	25	782	70	4.42	8.03
0659-0713	1.8	29	28	1113.5	12	810	71	4.36	8.2
0714-0728	1.7	29.5	161	1063.1	67	775	72	4.3	7.75
0729-0743	1.8	29.4	29	1065	12	776	72	4.3	7.76
0744-0804	1.5	30.7	42	899.5	17	656	72	4.3	6.55
0835-0859	1.7	28.9	27	1067.2	11	771	69	4.48	8.05
0900-0914	1.6	29.8	48	1161.8	20	840	69	4.48	8.76

STATISTICAL DATA

MEAN	1.7	29.5	68	1042	28	757	70.86	4.37	7.69
STD DEV	.16	.67	60.76	103.84	24.9	76.06	1.29	.08	.76
C195 MN	.09	.39	35.08	59.95	14.37	43.91	.75	.04	.44
(N)	14	14	14	14	14	14	14	14	14

MEASURED CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

MEASURED CLINKER RATE	EMISSION FACTORS
	MMBTU / TON CLINKER = 4.96
	LBS DRY FUEL / MMBTU = 691
	CO2 SCF / MMBTU = 2129
	TOT SCF / MMBTU = 11828
	NO LBS / SCF (3% O2) = 1.24 E-04
	NO LBS / MMBTU = 1.72
	NO LBS / TON CLINKER = 8.53
FEEDER REVS/TON CLINKER - 17	
CLINKER RATE (TON/HR) - 45.11	

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : FIVE CASINGS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL MNV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

SITE 4 ROTARY KILN

DATE - 3-3-84

TEST CONDITION - LOW % O2 COAL FLOW RATE (TON/HR) - 8.96**
 N2 FLOW RATE (SCFH) - NONE COAL HEAT VALUE (BTU/LB) - 12260

KILN EXIT DATA - DRY STACK GAS - EMISSION FACTORS (METHOD 2)*

TIME	O2 VOL% MEAS	CO2 VOL% MEAS	CO PPMV MEAS	NO PPMV 3%O2	CO MG/J --	NO MG/J --	KILN SPEED RPH	MMBTU / TON CLINKER	NO LB / TON CLINKER
1826-1838	.95	31.5	280	929	113	690	77	3.94	6.32
1839-1853	.8	31.6	278	975	112	724	77	3.94	6.64
1854-1908	.8	31.8	242	1032	97	766	77	3.94	7.03
1909-1923	.7	33	246	915	98	679	77	3.94	6.23
1924-1942	.5	33.1	776	725	309	541	79	3.84	4.84
1943-1957	.4	34.2	841	599	332	445	77	3.94	4.08
1958-2012	.4	31.9	582	750	227	550	73	4.16	5.32
2013-2027	.4	31.4	426	986	168	734	78	3.89	6.64
21116-2146	.6	33.9	412	794	164	589	77	3.94	5.41
2212-2223	.1	30.4	124	1081	51	814	82	3.7	7.01
2234-2248	.9	32.3	347	998	142	751	82	3.7	6.47

STATISTICAL DATA

MEAN	.7	32.3	414	889	165	662	77.82	3.9	6
STD DEV	.23	1.15	229.04	150.87	89.79	114.69	2.52	.13	.95
C195 MN	.15	.77	153.86	101.35	60.32	77.05	1.69	.09	.64
(N)	11	11	11	11	11	11	11	11	11

MEASURED CLINKER RATE AND EMISSIONS DATA (METHOD 2)*

MEASURED CLINKER RATE

EMISSION FACTORS

	MMBTU / TON CLINKER = 4.71
	LBS DRY FEED / MMBTU = 729
	CO2 SCF / MMBTU = 2245
	TOT SCF / MMBTU = 11944
	NO LBS / SCF (3% O2) = 1.06 E-04
	NO LBS / MMBTU = 1.48
	NO LBS / TON CLINKER = 6.97
FEEEDER REVS/TON CLINKER - 17	
CLINKER RATE (TON/HR) - 46.69	

NO ON A MASS BASIS IN TERMS OF NO2 -

* METHOD 2 : EVD CASEDUS EMISSIONS DATA (NO, O2), FUEL ANALYSIS, FUEL HHV, FUEL FLOW RATE, KILN FEEDER SPEED (CALCULATED FROM AVERAGE KILN SPEED)

** COAL FLOW RATE CORRECTED FOR MOISTURE (COAL SCALE/BURNER PIPE)

APPENDIX H

REPORT ON STATISTICAL ANALYSIS OF PRIMARY AIR
VITIATION WITH NITROGEN

ASSESSMENT OF COMBUSTION MODIFICATION TECHNOLOGY FOR NO_x CONTROL
IN CEMENT KILNS

FINAL REPORT

JANUARY 15, 1985

JAMES E. DUNN
FOR KVB

O. Summary

- (A) The structural difference equations approach is an effective means of modeling the cement kiln processes and isolating the individual effects of rotation speed, mill outlet O_2 , etc. In retrospect, it still seems to be the most effective empirical approach, having well-established theoretical foundations as well as readily available software for implementation.
- (B) Modification of the O_2 concentration in the primary air stream through N_2 injection does have a direct, statistically significant effect on reducing the NO_x concentration. Estimates of the effectiveness ranged from 16.4 ppm $NO/\%$ mill outlet O_2 to 76.0 ppm $NO/\%$ mill outlet O_2 , over the experimental region of 12.5% to 21% O_2 , depending on what other external conditions are held constant. No check was made of the linearity of this effect.
- (C) For future work, hood pressure should be recorded at the same frequency as the other variables of interest. Hood pressure variation, due to clinker buildup on the cooling grates, appears to be the main source of perturbation in the kiln operating process.
- (D) For future work, any observed time series should consist of 80 - 100 sequential data points with no discontinuities.

Assessment of Combustion Modification Technology for NO_x Control in Cement Kilns

1. Introduction

The assessment of NO_x control procedures in commercial scale cement kilns poses a special problem in that near-optimal operating conditions must be maintained during any testing period purely for economic reasons. Hence, any inference about the effectiveness of a control procedure must be made in the context of a model for a dynamic system subject to operator intervention and control. It is proposed here that such a model may not need to be extremely detailed, but rather that the structural equations approach so common in mathematical economics may provide an adequate framework for analysis. Basically, the process variables are divided into three types:

- (1) k exogenous variables, represented by the vector $\underline{x}_t$ at time t , whose values are determined by forces external to the system under study, e.g. the composition of the raw materials being fed into the cement kiln;
- (2) g endogenous variables, represented by the vector $\underline{y}_t$ at time t , whose values are determined by the simultaneous interactions of the variables within the system, e.g. the temperature of the burning zone; and
- (3) u lagged endogenous variables, represented by the vector $\underline{y}_t^L$ at time t , whose values are determined by the past history of the endogenous variables.

The composite consisting of the k exogenous and u lagged endogenous variables often is referred to as the set of predetermined variables.

A basic assumption is that these three types of variables can be related by a set of structural difference equations, typically of the linear form

$$G\underline{y}_t = C\underline{y}_t^L + B\underline{x}_t, \quad (1)$$

where G is a $g \times g$ matrix which is assumed to be nonsingular. C and B are $g \times u$ and $g \times k$ matrices respectively. Various statistical procedures have been developed and are available for estimating the parameter matrices (G , C , and B) in the above linear model as well as for nonlinear structural equations. Among the methods in common use are two and three stage least squares and limited information maximum likelihood. Most important in this context is the ability to test statistical hypotheses concerning the dynamic relationships among the variables.

In the context of the coal-fired, rotary cement kiln currently under study by KVB for EPA/IERL (Contract No. 08-02-3690), the main emphasis is to assess the effects of inert gas (N_2) input into the primary air stream as a means of NO_x control. Thus, assuming that a reasonably accurate structural model can be deduced for the kiln process, the critical feature will be to test the significance of the combined instantaneous and delayed relationships between the exogenous variable, mill outlet O_2 , and the exogenous variable, exhaust NO_x , as expressed by the reduced form model

$$y_t = G^{-1}C y_t^L + G^{-1}B x_t, \quad (2)$$

or its equivalent in terms of nonlinear structural equations.

An initial formulation of the structural equations, including choice of exogenous and lagged variables, was made on the basis of engineering considerations and a statistical analysis of a limited, base-line data set, identified here as KVB10-5 data. KVB10-5 data consisted of 71 sequential observations, sampled at six minute intervals, with mill outlet O_2 at its normal atmospheric level and with the coal feed rate held constant throughout this period. Tentative forms of the structural equations were defined and justified in a Preliminary Report to KVB, dated 11-9-84, and will only be reproduced here in limited form for easy reference. The primary task of the present report is to detail results of an analysis of an additional data set, referred to here as KVB4-17 data, in which the mill outlet O_2 level was caused to vary in a controlled fashion through use of N_2 injection.

The KVB4-17 data set consists of observations sampled at one minute intervals, beginning at 1503 on 4-17-84 and ending at 0054 on 4-18-84. For the purposes of modeling through use of the structural difference equations approach, this data set is severely handicapped due to 27 discontinuities in the data, the longest of which was 16 minutes. In an effort to circumvent this problem as well as better to utilize the previous attempt at model formulation, I sampled the KVB4-17 data in such a way as to generate six different subsets of data, each based on a six minute sampling interval. Since the longest discontinuity occurred from 1548 to 1603 on 4-17-84, I arbitrarily discarded the data from 1503 through 1547. Of the six data subsets thus generated, one, labeled Mod(6) = 4, had 16 missing values, no two of which were adjacent. In order to make this subset amenable for time series analysis, I then 'borrowed' whichever observed data point occurred closest to that which was

missing. Usually the resulting timing was off by only 1 - 2 minutes, but in three cases, it was off by four minutes. The next most complete data set, identified here as Mod(6) = 2 and beginning at 1504, involved 17 missing values, two of which were adjacent. Again, 'borrowing' the nearest observed values in order to complete the series resulted in three cases where the timing was off by four minutes. These two data subsets, each consisting of 87 complete observations, are included here as Appendices I and II for reference. In a sense, the separate analyses of each which are reported here provide a measure of replication, though certainly not independent results. The remaining four data subsets contained at least 20 missing values and hence were not utilized at all in arriving at this report. The presence of discontinuities in the original data set poses severe problems which could easily have been avoided during the sampling phase. Interpretation of the results presented here should be weighted against the ad hoc procedure which I used to fill in the missing values.

2. Model development

The primary endogenous variables which have been identified are as follows:

y_1 = exhaust NO_x (NO),

y_2 = exhaust O_2 (O2),

y_3 = kiln rotation speed (ROTAT),

y_4 = burning zone temperature (TEMP),

y_5 = exhaust CO (CO),

y_6 = exhaust CO_2 (CO2).

Initially, the coal feed rate (COAL) and the clinker rate (METH2) were to have been treated as endogenous variables as well. However, since adjustment of the coal feed rate is not normally used at this location as a primary control measure, COAL was designated as an exogenous variable instead. Even though Method 2 clinker rate was reported for the KVB4-17 data, since it was a computed value involving variables already incorporated in the structural equations, it was not used at all in the analyses reported here.

Two forms of structural equations are reported in the remainder of this section. Preliminary refers to the model arrived at on the basis of KVB10-5 data; final refers to the model which subsequently evolved from analysis of the

KVB4-17 data, using the preliminary model as a starting point, and with some final checking and adjusting against the KVB10-5 data.

Preliminary: $NO = f_1(TEMP, BURNF),$

Final: $NO = f_1(MILLO2, TEMP, MAA, ROTAT, COAL),$

where

BURNF = burnability factor,

MILLO2 = mill outlet O_2 (%),

$MAA = (BURNF)_t + (BURNF)_{t-1} + (BURNF)_{t-2}.$

Discussion. MILLO2 and COAL were added to f_1 for obvious reasons. The burnability factor moving average, MAA, replaced BURNF alone in order to account for blending effects which are likely to occur during passage through the kiln. As in the Preliminary Report, t in the MAA definition actually refers to a lag of 78 minutes, i.e. even though the feed chemistry data was sent already lagged by 90 minutes, I readjusted to account for a lag of only 78 minutes. This readjustment still seems to hold for the KVB4-17 data. Also, recall as before that each time unit here refers to six minutes of real time. ROTAT was added to f_1 both because it seemed to be an important predictor of variation in NO and because it is an obvious effect to be 'partialled out', i.e. held constant in the model when studying the influence of MILLO2 on NO.

Preliminary: $O_2 = f_2(MAH1, MASR),$

Final: $O_2 = f_2(MILLO2, MAH, MASR, COAL, MAA, CO_2),$

where

$MAH1 = (HOOD)_{t-3} + \dots + (HOOD)_{t-7},$

$MASR = (SR)_{t-6} + \dots + (SR)_{t-8},$

and MAH has been redefined from the Preliminary Report as

$MAH = (ROTAT)_{t-5} + \dots + (ROTAT)_{t-7}.$

Discussion. Again MILLO2 and COAL have been added for obvious reasons. MAA and CO_2 were added, based on their cross correlations with O_2 and several stages of residual analysis of the KVB4-17 data subsets. MAH, defined in terms of a moving average of the rotation speed, has been supplied as a surrogate for MAH1, a moving average of the hood pressure. In fact, it is a poor substitute and I would have used MAH1 rather than MAH had hood pressure been available. Since I am so thoroughly convinced that variation in hood pressure (due to clinker buildup on the cooling grates) is the key perturbing force in the kiln opera-

tion, I believe that it was a serious deficiency not to have recorded it at the same frequency as the other variables. Even though some occasional values were obtained, they do not reflect accurately the nearly instantaneous effects of changing hood pressure on flame length, burning zone conditions, etc.

Preliminary: $ROTAT = f_3(TEMP, O_2, NO, CO, DTEMP, DCO_2),$

Final: $ROTAT = f_3(TEMP, O_2, NO, CO, DTEMP, DCO_2, COAL, MAA, MCO_2, HOOD),$

where

$$DTEMP = (TEMP)_t - (TEMP)_{t-1},$$

$$DCO_2 = (CO_2)_t - (CO_2)_{t-3},$$

$$MCO_2 = (CO_2)_t + \dots + (CO_2)_{t-3},$$

$HOOD =$ instantaneous hood pressure.

Discussion. MAA and MCO₂ were added on the basis of a residual analysis of the preliminary model when applied to the KVB4-17 subsets. COAL appears to be a marginal variable, though one would suppose that the operator surely would be aware of any changes which were made in the coal feed rate. HOOD, as measured in the KVB4-17 data, probably acts more as a moving average than an instantaneous value. I would replace it by the original definition

$$MAH = (HOOD)_t + \dots + (HOOD)_{t-3}$$

if instantaneous HOOD values were available.

Preliminary: $TEMP = f_4(FLUX, MAR, MAA, MAH, MAF, MCO_2),$

Final: (Same as above),

where

$$MAR = (ROTAT)_t + \dots + (ROTAT)_{t-3},$$

$$MAF = (ROTAT)_{t-8} + \dots + (ROTAT)_{t-12},$$

and MAH is the revised definition in terms of kiln rotation speed.

Discussion. Recall that the long lags in the MAF definition actually reflect the effect of varying the feeder speed at an earlier epoch in time by varying the rotation speed. Use of moving averages almost exclusively here is logical in that TEMP cannot respond immediately to changing internal conditions, since there is always considerable mass to be heated or cooled. I attempted a moving average of FLUX, but it was not as effective a predictor as instantaneous FLUX.

Of course, FLUX as used here was already lagged by 78 minutes.

Preliminary: $CO = f_5(TEMP, ROTAT, O_2),$

Final: $CO = f_5(TEMP, ROTAT, O_2, MAF, COAL, MILLO_2).$

Discussion. The nature of the CO pulse phenomenon has not been clarified by the KVB4-17 data analysis. I suspect that it is associated with some threshold of one or more variables. Clearly, I have included the obvious variables in the model, but with little apparent success.

Preliminary: $CO_2 = f_6(MAF, MASR1, BURNF, FLUX),$

Final: $CO_2 = f_6(MAF, MAA, FLUX, MAR, O_2, DCO_2),$

where

$$MASR1 = (SR)_{t-13} + \dots + (SR)_{t-15}.$$

Discussion. MAA effectively replaces both SR and BURNF in the preliminary model (BURNF being already a function of SR). Besides that, a lag of 78 to 90 minutes in addition to the 78 minute lag already built into the SR data seemed surely based on spurious cross correlations. MAR, O₂, and DCO₂ were added, based on a residual analysis of the preliminary model when applied to the KVB4-17 data.

3. Results

A summary of the final structural equations is given in Table 1. This includes six behavioral equations (for NO, O₂, ROTAT, TEMP, CO, and CO₂), followed by eight identities which define the moving averages and the rates of change of TEMP and CO₂. This actually constitutes a simplification of the structural equations given in the Preliminary Report since fewer identities are involved, the moving averages are generally based on fewer terms, and the time delays are shorter. A summary of the two stage least squares estimation results is given in Table 2 for the KVB4-17, Mod(6) = 2 data subset. The particular statistics of interest include (1) R-SQUARE (R^2) which represents the fraction of the variability in the response variable (DEP VAR) which has been accounted for in terms of the variability of the predictor variables in the model; (2) the estimated coefficients of the structural equations, particularly that for MILLO₂ in the NO model, and their standard errors; and (3) the tests of significance of R^2 and the individual regression coefficients, particularly that for MILLO₂.

The crucial point in interpreting these fitted models is that when a variable appears in a model, then its effect is effectively 'partialled out', i.e. held

TABLE 1.

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS

MODEL NO	=	MILLO2 BOO1.TEMP BOO1.MAA BOO1.ROTAT COAL
MODEL O2	=	BOO1.MAH BOO1.MASR MILLO2 COAL BOO1.MAA BOO1.CO2
MODEL ROTAT	=	BOO1.TEMP BOO1.O2 BOO1.NO BOO1.CO BOO1.DTEMP COAL BOO1.MAA BOO1.MCO2 BOO1.DCO2 HOOD
MODEL TEMP	=	BOO1.MAR BOO1.MAA BOO1.MAH BOO1.MAF BOO1.MCO2 FLUX
MODEL CO	=	BOO1.TEMP BOO1.ROTAT BOO1.O2 BOO1.MAF COAL MILLO2
MODEL CO2	=	BOO1.MAF BOO1.MAA FLUX BOO1.MAR BOO1.O2 BOO1.DCO2
IDENTITY	+	MAR - ROTAT - R1 - R2 - R3 = 0.00
IDENTITY	+	MAA - BURNF - A1 - A2 = 0.00
IDENTITY	+	MAH - R5 - R6 - R7 = 0.00
IDENTITY	+	MAF - R8 - R9 - R10 - R11 - R12 = 0.00
IDENTITY	+	MCO2 - CO2 - CO21 - CO22 - CO23 = 0.00
IDENTITY	+	MASR - SR - SR1 - SR2 - SR3 = 0.00
IDENTITY	+	DTEMP - TEMP + TEMP1 = 0.00
IDENTITY	+	DCO2 - CO2 + CO23 = 0.00

TABLE 2.
ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS

MODEL: A	SSE	945715.1	F RATIO	37.73
	DFF	69	APPROX PROF	0.0001
DEP VAR: NO	MSE	13706.02	R-SQUARE	0.7322
	OBJ	1025697		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	1215.68	3505.853	0.3468	0.7298
MILLO2	1	51.422251	9.364683	5.4911	0.0001
B001.TEMP	1	3.540384	0.583340	6.0692	0.0001
B001.MAA	1	-13.713900	5.583334	-2.4562	0.0166
B001.ROTAT	1	-6.091724	6.279239	-0.9701	0.3354
COAL	1	-524.034552	111.680071	-4.6839	0.0001

MODEL: B	SSE	12.448442	F RATIO	18.61
	DFF	68	APPROX PROF	0.0001
DEP VAR: O2	MSE	0.183065	R-SQUARE	0.6216
	OBJ	17.986051		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	9.163852	8.157440	1.1234	0.2652
B001.MAH	1	0.001643679	0.009933895	0.1655	0.8691
B001.MASK	1	-0.185416	0.166346	-1.1146	0.2689
MILLO2	1	0.153628	0.034508	4.4519	0.0001
COAL	1	-0.600940	0.431310	-1.3933	0.1681
B001.MAA	1	0.013812	0.016950	0.8149	0.4180
B001.CO2	1	-0.255956	0.069528	-3.6813	0.0005

MODEL: D	SSE	214.681016	F RATIO	25.95
	DFF	64	APPROX PROF	0.0001
DEP VAR: ROTAT	MSE	3.357516	R-SQUARE	0.8022
	OBJ	174.042566		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-183.277788	49.902856	-3.6727	0.0005
B001.TEMP	1	0.084270	0.015552	5.4188	0.0001
B001.O2	1	0.458565	0.946586	0.4844	0.6297
B001.NO	1	-0.00966399	0.003139838	-3.0779	0.0031
B001.CO	1	-0.00155839	0.002897501	-0.5378	0.5926
B001.DTEMP	1	-0.044858	0.028531	-1.5722	0.1208
COAL	1	-4.054265	1.865699	-2.1731	0.0335
B001.MAA	1	0.103564	0.072441	1.4296	0.1577
B001.MCO2	1	0.379025	0.071775	5.2807	0.0001
B001.DCO2	1	0.136831	0.167864	0.8151	0.4180
HOOD	1	-134.421655	23.237761	-5.7846	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS

MODEL: E	SSE	47961.66	F RATIO	25.70
	DFE	68	APPROX PROB	0.0001
DEP VAR: TEMP	MSE	705.318602	R-SQUARE	0.6940
	OBJ	45757.61		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	4259.774	355.624457	11.9783	0.0001
B001.MAR	1	2.213472	0.406000	5.4519	0.0001
B001.MAA	1	-4.535983	0.590351	-7.6835	0.0001
B001.MAH	1	-0.571313	0.755831	-0.7559	0.4523
B001.MAF	1	0.831923	0.325991	2.5520	0.0130
B001.MC02	1	-4.129464	1.201723	-3.4363	0.0010
FLUX	1	-19.067739	7.073853	-2.6955	0.0088

MODEL: G	SSE	1847723	F RATIO	1.15
	DFE	68	APPROX PROB	0.3425
DEP VAR: CO	MSE	27172.39	R-SQUARE	0.0921
	OBJ	2039858		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1860.23	1948.665	-0.9546	0.3432
B001.TEMP	1	0.883081	0.557848	1.5830	0.1181
B001.ROTAT	1	-7.613096	7.466767	-1.0196	0.3115
B001.O2	1	-65.074270	66.175342	-0.9834	0.3269
B001.MAF	1	-1.918131	1.636068	-1.1724	0.2451
COAL	1	88.652623	141.490651	0.6266	0.5330
MILLO2	1	5.622137	13.136224	0.4280	0.6700

MODEL: H	SSE	57.392943	F RATIO	34.94
	DFE	68	APPROX PROB	0.0001
DEP VAR: CO2	MSE	0.844014	R-SQUARE	0.7551
	OBJ	96.567860		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	0.661419	12.421495	0.0532	0.9577
B001.MAF	1	0.011559	0.012141	0.9521	0.3444
B001.MAA	1	0.090442	0.025400	3.5607	0.0007
FLUX	1	-0.517118	0.266565	-1.9399	0.0565
B001.MAR	1	0.040066	0.012171	3.2919	0.0016
B001.O2	1	-1.283330	0.365766	-3.5086	0.0008
B001.DC02	1	0.194931	0.085063	2.2916	0.0250

constant, so far as interpreting the effects of the other variables in the model. Conversely, the effect of any variable not included in the model is not 'partialled out' so far as the variables which are included in the model. Specifically for the KVB4-17, Mod(6) = 2 data subset, if TEMP, MAA, ROTAT, and COAL were held constant, then the effect of raising MILLO2 is estimated to be 51.4 ppm NO for each additional percent of O₂ in the experimental range of 12.5% - 21% O₂, with a standard error of 9.4 ppm. An asymptotic t-test of the null hypothesis that changing MILLO2 under these controlled conditions has no effect on NO indicates that the estimate is significantly different from zero at the 0.0001 level ($P < 0.0001$).

Now suppose that control of each of the four variables, TEMP, MAA, ROTAT, and COAL, is relaxed one at a time, i.e. by removing that variable from the NO model. The resulting estimated effects of varying MILLO2 under these conditions are given in Table 3. Clearly, only a novice operator would allow TEMP to be uncontrolled in order to maintain constant ROTAT. On the other hand, it is feasible to allow variation in ROTAT in order to maintain constant TEMP, in the presence of constant MAA and COAL, thus leading to an estimate of 53.3 ppm NO/% MILLO2, with a standard error of 9.2 ppm. Clearly, it is of concern to me whether or not it is physically possible to vary MILLO2 while holding the remaining four variables constant in the first model! On the other hand, the signs of the estimated coefficients appear to be physically meaningful, e.g. NO increases as TEMP increases, NO decreases as ROTAT increases, etc.

Comparable results for the KVB4-17, Mod(6) = 4 data subset are given in Tables 4 and 5, where the corresponding estimates are 41.8 ppm NO/% MILLO2 (s.e. = 8.6 ppm) and 42.9 ppm NO/% MILLO2 (s.e. = 8.5 ppm) respectively. Clearly, the two pairs of estimates are well within two standard errors of each other and thus appear to be consistent. Note also that the effect of varying MILLO2 remains highly significant for all the models in Tables 2 - 5. The actual effect depends on what is held constant (by the model) and what is not. The adequacy of fit of these models seems comparable to that obtained for the KVB10-5 data, with most R^2 being 0.7 or higher with the familiar exception being the CO model.

Tables 6 - 7 repeat this analysis using the same form of structural equations, but using NO (corrected), denoted by NDC, in addition to NO as an exogenous variable with the identical set of predictors. However, NO rather than NDC was retained in the ROTAT model even in this analysis since the operator surely is surely aware of NO rather than NDC. Thus, estimates of the structural equations

TABLE 3.

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1676510	F RATIO	21.72
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	23950.15	R-SQUARE	0.5538
	OBJ	1530554		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	19700.43	2295.238	8.5832	0.0001
MILLO2	1	76.007025	11.161134	6.8100	0.0001
B001.MAA	1	-39.606076	4.761271	-8.3184	0.0001
B001.ROTAT	1	21.809012	5.654146	3.8572	0.0003
COAL	1	-671.598029	127.051141	-6.8602	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
MAA UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1024841	F RATIO	42.74
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	14640.58	R-SQUARE	0.7095
	OBJ	1108386		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-7035.9	1036.127	-6.7906	0.0001
MILLO2	1	33.591804	6.114437	5.4939	0.0001
B001.TEMP	1	4.635186	0.388934	11.9177	0.0001
B001.ROTAT	1	-14.857971	5.339576	-2.7826	0.0069
COAL	1	-326.599747	80.429428	-4.0607	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
ROTAT UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	978813.8	F RATIO	46.00
	DFE	70	APPROX PROB	0.0001
DEP VAR: NO	MSE	13983.05	R-SQUARE	0.7244
	OBJ	1038597		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	3344.652	2761.566	1.2111	0.2299
MILLO2	1	53.326146	9.248819	5.7657	0.0001
B001.TEMP	1	3.126064	0.401355	7.7888	0.0001
B001.MAA	1	-16.792591	4.639970	-3.6191	0.0006
COAL	1	-577.255490	96.467550	-5.8612	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1245315	F RATIO	32.11
	DFE	70	APPROX PROB	0.0001
DEP VAR: NO	MSE	17790.22	R-SQUARE	0.6472
	OBJ	1326392		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-11926.7	2394.713	-4.9804	0.0001
MILLO2	1	19.251312	7.252393	2.6545	0.0098
B001.ROTAT	1	-20.513236	6.234839	-3.2901	0.0016
B001.TEMP	1	4.938947	0.570932	8.6507	0.0001
B001.MAA	1	5.075134	4.424532	1.1470	0.2553

TABLE 4.
ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS

MODEL: A	SSE	1019952	F RATIO	31.01
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	14781.92	R-SQUARE	0.6920
	OBJ	1181064		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-2821.05	3293.792	-0.8565	0.3947
MILLO2	1	41.789689	8.584644	4.8680	0.0001
B001.TEMP	1	3.586693	0.572208	6.2682	0.0001
B001.MAA	1	-4.916455	5.250828	-0.9363	0.3524
B001.ROTAT	1	-5.177294	6.222215	-0.8321	0.4082
COAL	1	-403.006574	106.927745	-3.7690	0.0003

MODEL: B	SSE	9.462506	F RATIO	31.78
	DFE	68	APPROX PR>F	0.0001
DEP VAR: O2	MSE	0.139154	R-SQUARE	0.7371
	OBJ	16.389069		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	11.829473	6.750138	1.7525	0.0842
B001.MAH	1	0.015832	0.007445184	2.1265	0.0371
B001.MASR	1	-0.232630	0.158560	-1.4671	0.1469
MILLO2	1	0.151501	0.027406	5.5280	0.0001
COAL	1	-1.003393	0.401191	-2.5010	0.0148
B001.MAA	1	0.013597	0.013504	1.0070	0.3175
B001.CO2	1	-0.294898	0.063322	-4.6571	0.0001

MODEL: D	SSE	170.016778	F RATIO	34.85
	DFE	64	APPROX PR>F	0.0001
DEP VAR: ROTAT	MSE	2.656512	R-SQUARE	0.8448
	OBJ	160.021908		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-234.057022	45.524500	-5.1413	0.0001
B001.TEMP	1	0.070602	0.012459	5.6669	0.0001
B001.O2	1	-2.355874	0.725846	-3.2457	0.0019
B001.NO	1	-0.00296559	0.002559917	-1.1585	0.2510
B001.CO	1	-0.00423199	0.001640135	-2.5803	0.0122
B001.DTEMP	1	-0.085156	0.021799	-3.9064	0.0002
COAL	1	-2.616290	1.743983	-1.5002	0.1385
B001.MAA	1	0.369930	0.060877	6.0767	0.0001
B001.MCO2	1	0.222971	0.061238	3.6411	0.0005
B001.DCO2	1	-0.540309	0.193711	-2.7893	0.0070
HOOD	1	-114.401558	18.166941	-6.2972	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS

MODEL: E	SSE	38400.75	F RATIO	39.85
	DFE	68	APPROX PROB	0.0001
DEP VAR: TEMP	MSE	564.716971	R-SQUARE	0.7786
	OBJ	37416.54		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB>T:
INTERCEPT	1	4725.629	313.695565	15.0644	0.0001
B001.MAR	1	2.740154	0.341972	8.0128	0.0001
B001.MAA	1	-5.884665	0.504633	-11.6613	0.0001
B001.MAH	1	0.866956	0.537783	1.6121	0.1116
B001.MAF	1	0.115254	0.263737	0.4370	0.6635
B001.MCO2	1	-5.870330	0.825899	-7.1078	0.0001
FLUX	1	-19.428893	6.011938	-3.2317	0.0019

MODEL: G	SSE	2445244	F RATIO	3.24
	DFE	68	APPROX PROB	0.0074
DEP VAR: CO	MSE	35959.47	R-SQUARE	0.2221
	OBJ	2756481		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB>T:
INTERCEPT	1	-3646.73	2459.966	-1.4824	0.1428
B001.TEMP	1	1.921624	0.621414	3.0923	0.0029
B001.ROTAT	1	-16.889107	8.510930	-1.9844	0.0512
B001.O2	1	-85.974900	67.861467	-1.2669	0.2095
B001.MAF	1	-2.599147	1.435095	-1.8111	0.0745
COAL	1	82.126032	203.268951	0.4040	0.6875
MILLO2	1	11.294909	14.297465	0.7900	0.4323

MODEL: H	SSE	51.352821	F RATIO	35.18
	DFE	68	APPROX PROB	0.0001
DEP VAR: CO2	MSE	0.755189	R-SQUARE	0.7564
	OBJ	85.599418		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB>T:
INTERCEPT	1	13.380843	12.015032	1.1137	0.2693
B001.MAF	1	0.00691983	0.00792943	0.8727	0.3859
B001.MAA	1	0.081598	0.024934	3.2725	0.0017
FLUX	1	-0.728912	0.216358	-3.3690	0.0012
B001.MAR	1	0.029871	0.011676	2.5584	0.0127
B001.O2	1	-1.363449	0.255148	-5.3438	0.0001
B001.DCO2	1	0.063709	0.086033	0.7405	0.4615

TABLE 5.

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1672685	F RATIO	15.99
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	26752.64	R-SQUARE	0.4775
	OBJ	1761844		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	14962.49	2251.037	6.6469	0.0001
MILLO2	1	61.372913	10.756927	5.7054	0.0001
BOO1.MAA	1	-29.640825	4.662696	-6.3570	0.0001
BOO1.ROTAT	1	23.243325	5.732560	4.0546	0.0001
COAL	1	-698.075790	129.159361	-5.4048	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
MAA UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1021874	F RATIO	39.03
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	14598.2	R-SQUARE	0.6904
	OBJ	1194023		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-5752.7	1016.217	-5.6609	0.0001
MILLO2	1	35.950834	5.863129	6.1317	0.0001
BOO1.TEMP	1	3.989164	0.375344	10.6280	0.0001
BOO1.ROTAT	1	-8.359305	5.179674	-1.6139	0.1111
COAL	1	-338.587081	81.343289	-4.1624	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
ROTAT UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1050076	F RATIO	38.03
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	15001.08	R-SQUARE	0.6848
	OBJ	1191298		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1145.83	2626.086	-0.4363	0.6639
MILLO2	1	42.895878	8.543720	5.0207	0.0001
BOO1.TEMP	1	3.239749	0.394762	8.2068	0.0001
BOO1.MAA	1	-7.302716	4.430951	-1.6481	0.1038
COAL	1	-442.327302	96.626877	-4.5777	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO MODEL.

MODEL: A	SSE	1207086	F RATIO	30.19
	DFE	70	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	17244.08	R-SQUARE	0.6330
	OBJ	1391042		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-12148.2	2347.704	-5.1745	0.0001
MILLO2	1	20.011661	6.857244	2.9183	0.0047
BOO1.TEMP	1	4.536134	0.554914	8.1745	0.0001
BOO1.MAA	1	7.817171	4.341397	1.8006	0.0761
BOO1.ROTAT	1	-15.541595	6.028528	-2.5780	0.0120

TABLE 6.

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS, USING NO(CORRECTED) RATHER THAN NO.

MODEL: AA	SSE	1495273	F RATIO	19.68
	DFE	69	APPROX PROB	0.0001
DEP VAR: NOC	MSE	21670.62	R-SQUARE	0.5902
	OBJ	1582344		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	3839.871	4408.327	0.8710	0.3867
MILLO2	1	55.054612	11.775331	4.6754	0.0001
B001.ROTAT	1	-6.564942	7.895635	-0.8315	0.4086
B001.MAA	1	-15.835364	7.020591	-2.2556	0.0273
B001.TEMP	1	2.944481	0.733503	4.0143	0.0001
COAL	1	-580.151907	140.680130	-4.1239	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	2056410	F RATIO	15.36
	DFE	70	APPROX PROB	0.0001
DEP VAR: NOC	MSE	29377.28	R-SQUARE	0.4674
	OBJ	1931553		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	19213.35	2542.023	7.5583	0.0001
MILLO2	1	75.501381	12.361183	6.1079	0.0001
B001.ROTAT	1	16.639661	6.262082	2.6572	0.0098
B001.MAA	1	-37.369478	5.273205	-7.0867	0.0001
COAL	1	-869.214972	140.711723	-6.1773	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
MAA UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1583859	F RATIO	22.58
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	22626.56	R-SQUARE	0.5634
	OBJ	1692595		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T :
INTERCEPT	1	-5688.18	1288.081	-4.4160	0.0001
MILLO2	1	34.465893	7.601276	4.5342	0.0001
B001.ROTAT	1	-16.687279	6.637993	-2.5139	0.0142
B001.TEMP	1	4.208643	0.483511	8.7043	0.0001
COAL	1	-352.175034	99.987335	-3.5222	0.0008

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
ROTAT UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1543583	F RATIO	24.25
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	22051.18	R-SQUARE	0.5808
	OBJ	1597326		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T :
INTERCEPT	1	6134.227	3467.93	1.7686	0.0813
MILLO2	1	57.106405	11.614519	4.9168	0.0001
B001.MAA	1	-19.153215	5.826800	-3.2871	0.0016
B001.TEMP	1	2.497977	0.504015	4.9562	0.0001
COAL	1	-637.507161	123.679084	-5.1545	0.0001

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1836842	F RATIO	17.01
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	26240.61	R-SQUARE	0.4929
	OBJ	1950888		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T :
INTERCEPT	1	-10709.9	2908.37	-3.6824	0.0005
MILLO2	1	19.438578	8.808006	2.2069	0.0306
B001.ROTAT	1	-22.530813	7.572190	-2.9755	0.0040
B001.MAA	1	4.965734	5.373578	0.9241	0.3586
B001.TEMP	1	4.492812	0.693395	6.4794	0.0001

TABLE 7.

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS, USING NO(CORRECTED) RATHER THAN NO.

MODEL: AA	SSE	1213561	F RATIO	24.39
	DFE	69	APPROX PROB	0.0001
DEP VAR: NOC	MSE	17567.64	R-SQUARE	0.6367
	OBJ	1352375		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1284.91	3592.632	-0.3576	0.7217
MILLO2	1	47.620320	9.364038	5.0854	0.0001
B001.ROTAT	1	-6.679145	6.787125	-0.9841	0.3285
B001.TEMP	1	3.330252	0.624158	5.3356	0.0001
B001.MAA	1	-4.214715	5.727546	-0.7359	0.4643
COAL	1	-530.869390	116.635633	-4.5515	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1955685	F RATIO	14.71
	DFE	70	APPROX PROB	0.0001
DEP VAR: NOC	MSE	27938.35	R-SQUARE	0.4567
	OBJ	1853075		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	15227.15	2300.381	6.6194	0.0001
MILLO2	1	65.803382	10.992724	5.9861	0.0001
B001.ROTAT	1	19.709456	5.858220	3.3644	0.0012
B001.MAA	1	-27.171342	4.764905	-5.7024	0.0001
COAL	1	-804.841745	131.990602	-6.0977	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
MAA UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1213461	F RATIO	30.80
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	17335.15	R-SQUARE	0.6376
	OBJ	1361898		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-3798.11	1107.39	-3.4298	0.0010
MILLO2	1	42.614861	6.389159	6.6699	0.0001
BOO1.ROTAT	1	-9.406979	5.644386	-1.6666	0.1001
BOO1.TEMP	1	3.675277	0.409019	6.9856	0.0001
COAL	1	-475.644678	88.641275	-5.3660	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
ROTAT UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1258692	F RATIO	29.58
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	17981.31	R-SQUARE	0.6263
	OBJ	1369407		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	876.269817	2875.136	0.3048	0.7614
MILLO2	1	49.047397	9.353979	5.2435	0.0001
BOO1.MAA	1	-7.293194	4.851168	-1.5034	0.1372
BOO1.TEMP	1	2.882665	0.432200	6.6697	0.0001
COAL	1	-581.596441	105.790670	-5.4976	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO(CORRECTED) MODEL.

MODEL: AA	SSE	1552470	F RATIO	20.07
	DFE	70	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	22178.14	R-SQUARE	0.5342
	OBJ	1716730		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-13571.4	2662.477	-5.0973	0.0001
MILLO2	1	18.932727	7.776642	2.4346	0.0175
BOO1.ROTAT	1	-20.331752	6.836814	-2.9739	0.0040
BOO1.MAA	1	12.558938	4.923478	2.5508	0.0129
BOO1.TEMP	1	4.580924	0.629315	7.2792	0.0001

H-23

for NO, O2, ROTAT, TEMP, CO, and CO2 remain the same as given in Tables 2 and 4 and thus are not reproduced again as part of Tables 6 and 7. Even though R^2 for the NDC model is somewhat less than that for NO in both cases, the estimated effects of varying MILLO2 under varying degrees of control are quite comparable. Significance levels of the effect of MILLO2 are also maintained for NDC.

One of the puzzling aspects (to me) is how uncontrolled variation in COAL seems to cancel approximately half the effect of varying MILLO2. Does this have a physical explanation?

In summarizing Tables 2 - 7, you may wish to list 0.95 confidence intervals for the true coefficients as

Estimate $\pm$ 2 s.e.,

where s.e. is the standard error listed beside the corresponding estimate. Use of 2 actually agrees very well with the critical value of t for slightly more than 60 degrees of freedom, i.e. $t_{(60)0.975} = 2.000$.

In addition to use of R^2 as a measure of fit, the adequacy of fit also is reflected in Figures 1 - 6 which show the observed series (O) for each endogenous variable in the KVB4-17, Mod(6) = 2 data subset with the fitted series (P) superimposed. In these figures, the fitted series were obtained by substituting observed values of exogenous variables in the estimated structural equations, e.g. the current value of TEMP in predicting the current value of NO. The R^2 listed in the previous tables reflects the agreement between O and P.

By contrast, Figures 7 - 12 again show the observed series (O) with fitted series (P) superimposed, but in this case, the fitted values were forecast from past forecasted values of all endogenous predictors in the models as well as the current values of any exogenous variables. Hence, adequacy of the models is much more difficult to attain in this situation since errors in forecasting the endogenous variables are likely to be accumulative.

Figures 13 - 24 repeat the format described above, but for the KVB4-17, Mod(6) = 4 data subset. In general, the structural equations both fit and forecast very well for NO, ROTAT, and TEMP; do an adequate job for O2 and CO2 in the presence of very erratic observed series; and do quite poorly with respect to the pulsed CO series.

In order to check for consistency, the final model based on the KVB4-17 data analysis was applied to the original KVB10-5 data set, with the estimated structural equations as shown in Table 8. Both COAL and MILLO2 do not appear in these models since they were held constant during that test period. Plots of the

FIGURE 1.
ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF NO*T SYMBOL USED IS O
PLOT OF PNO*T SYMBOL USED IS P

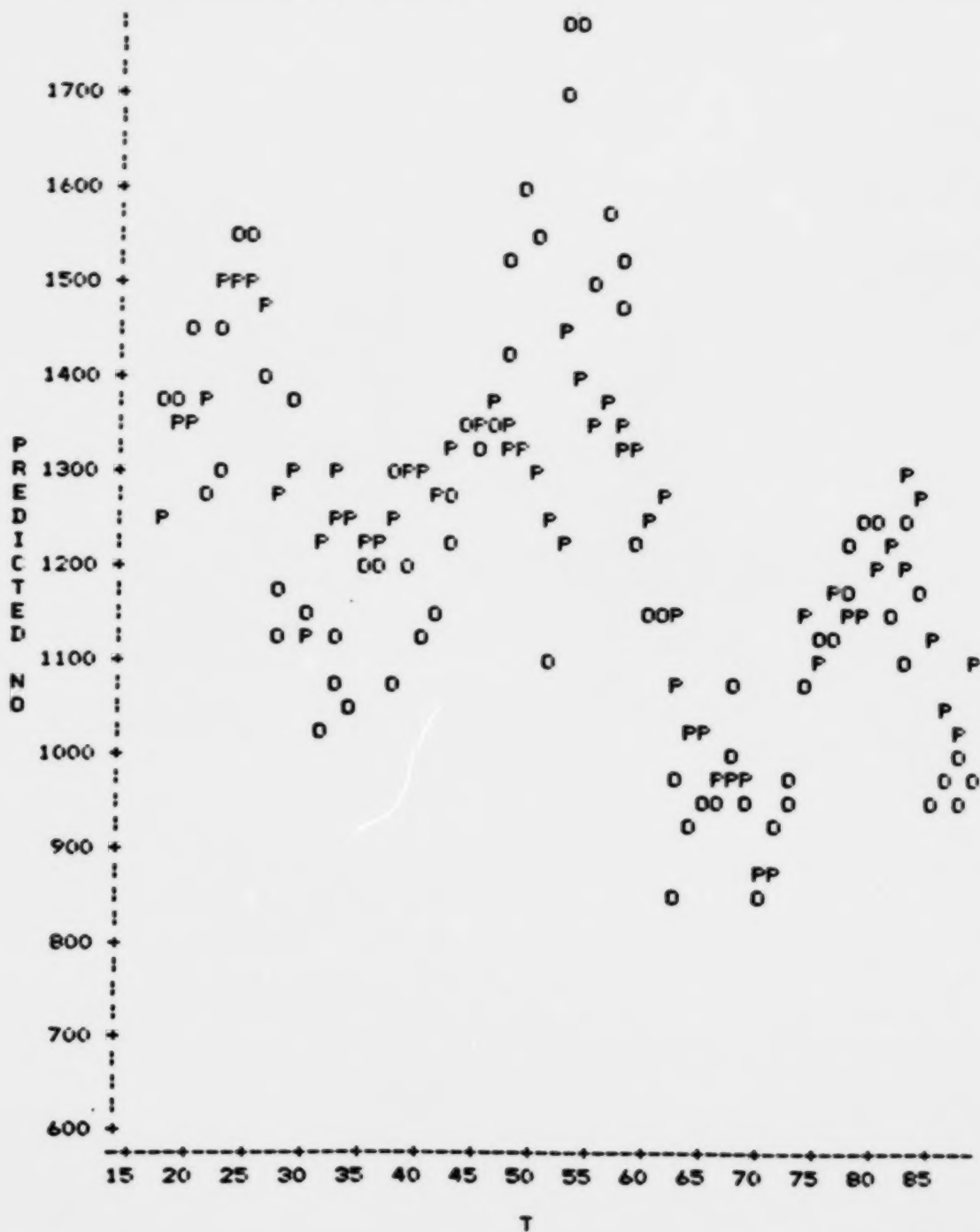


FIGURE 2.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF D2*T SYMBOL USED IS O
PLOT OF P02*T SYMBOL USED IS P

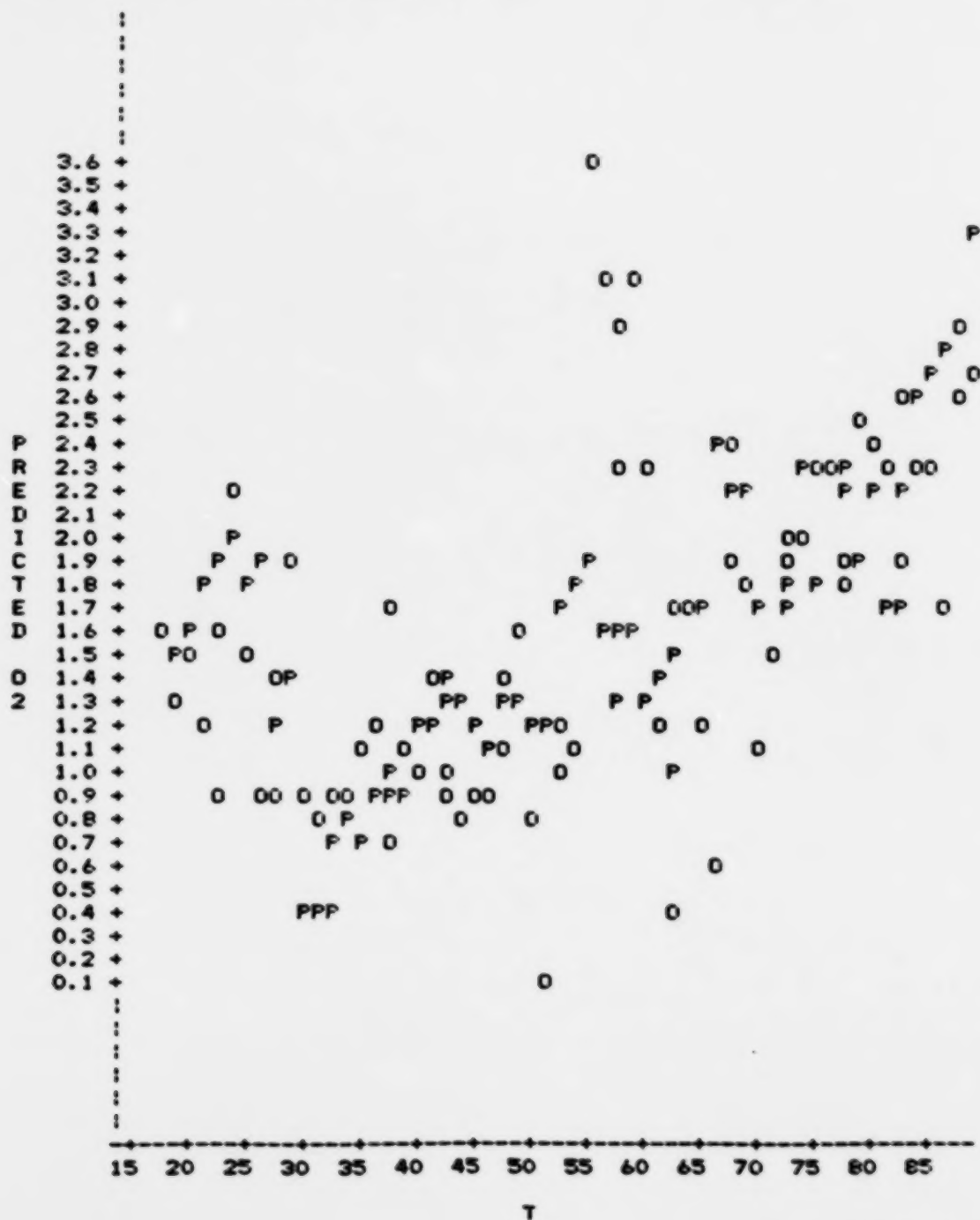


FIGURE 3.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF ROTAT*T SYMBOL USED IS O
 PLOT OF PROTAT*T SYMBOL USED IS P

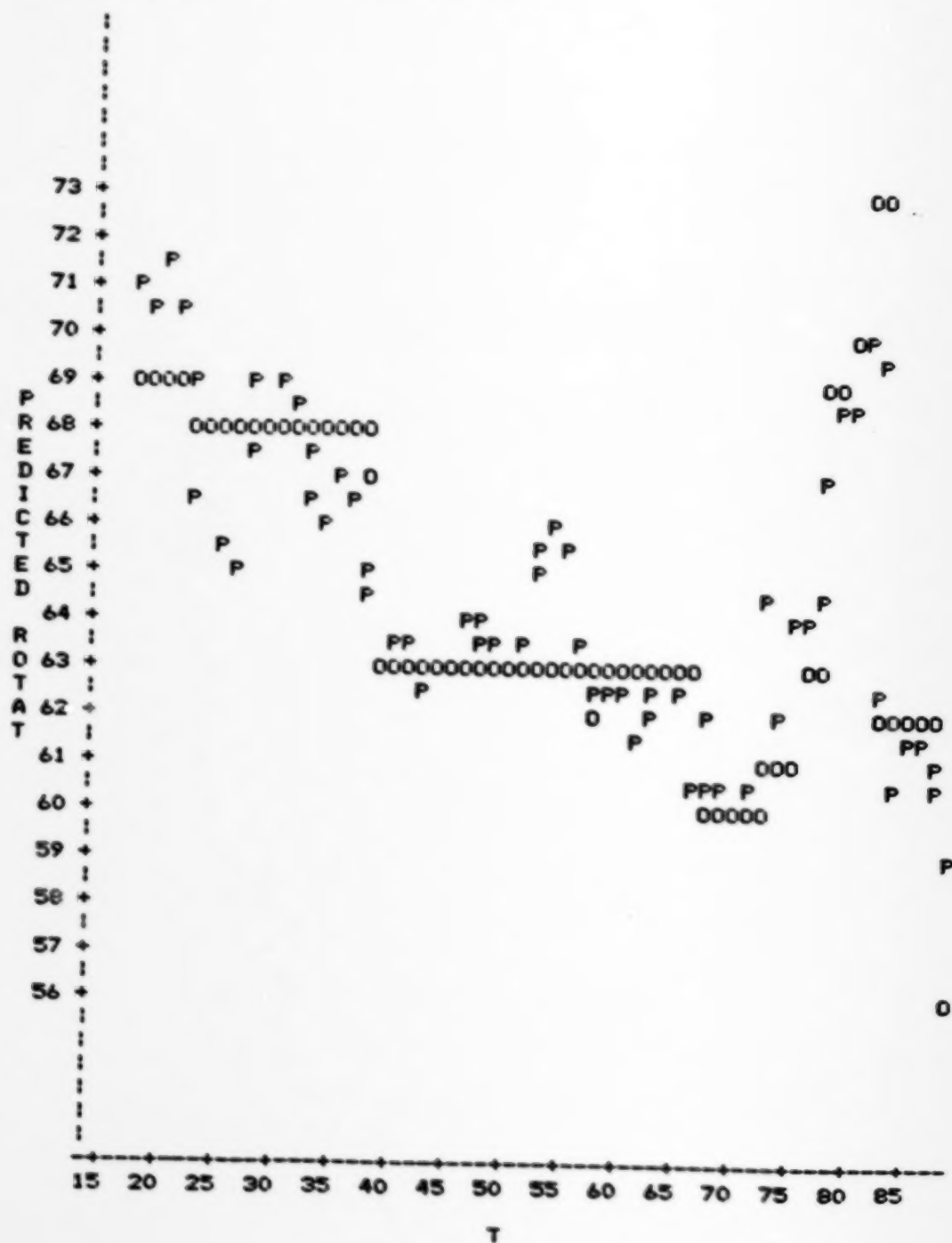


FIGURE 4.
ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF TEMP*T SYMBOL USED IS O
PLOT OF PTEMP*T SYMBOL USED IS P

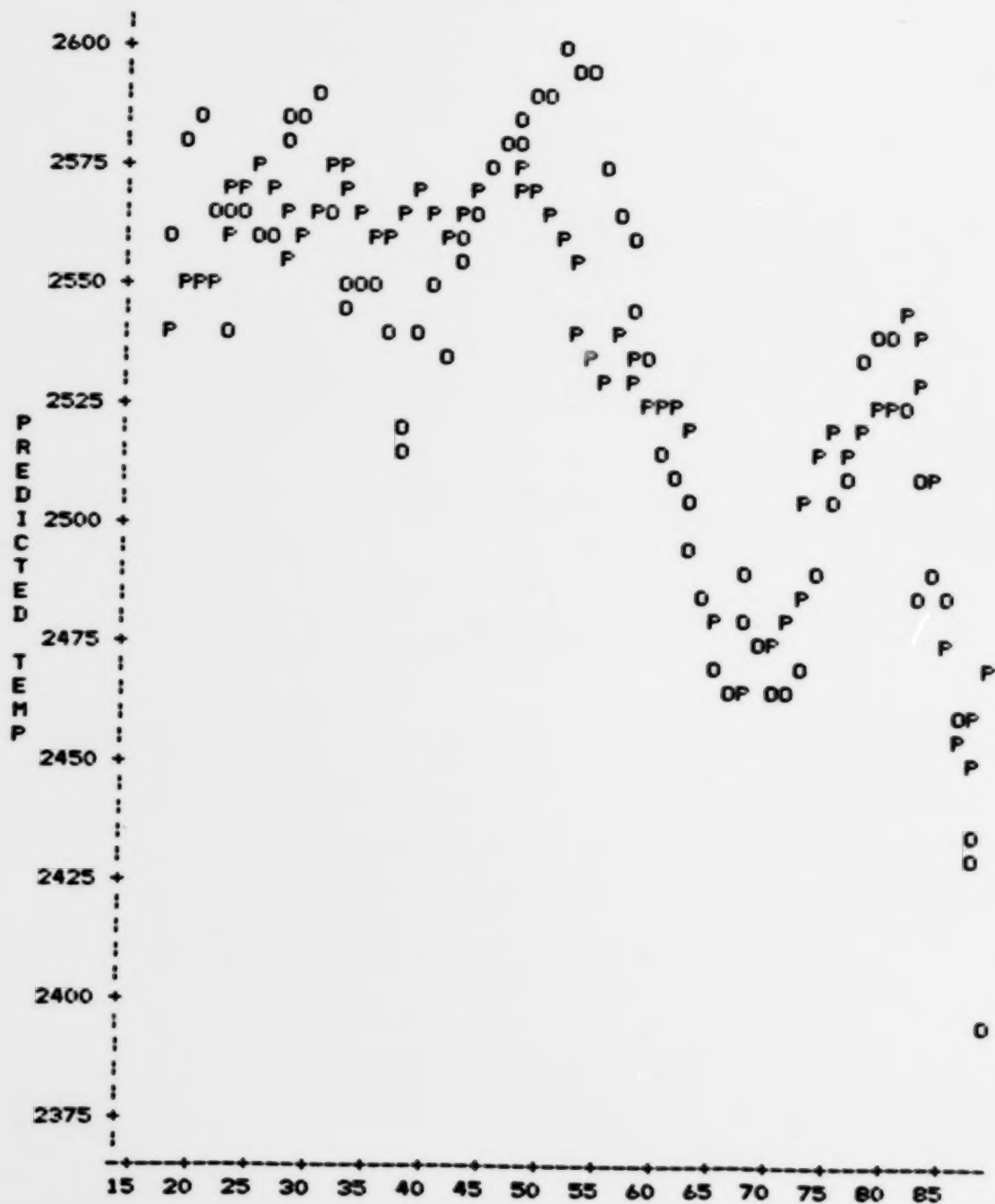


FIGURE 5.
ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF CO*T SYMBOL USED IS O
PLOT OF PCO*T SYMBOL USED IS P

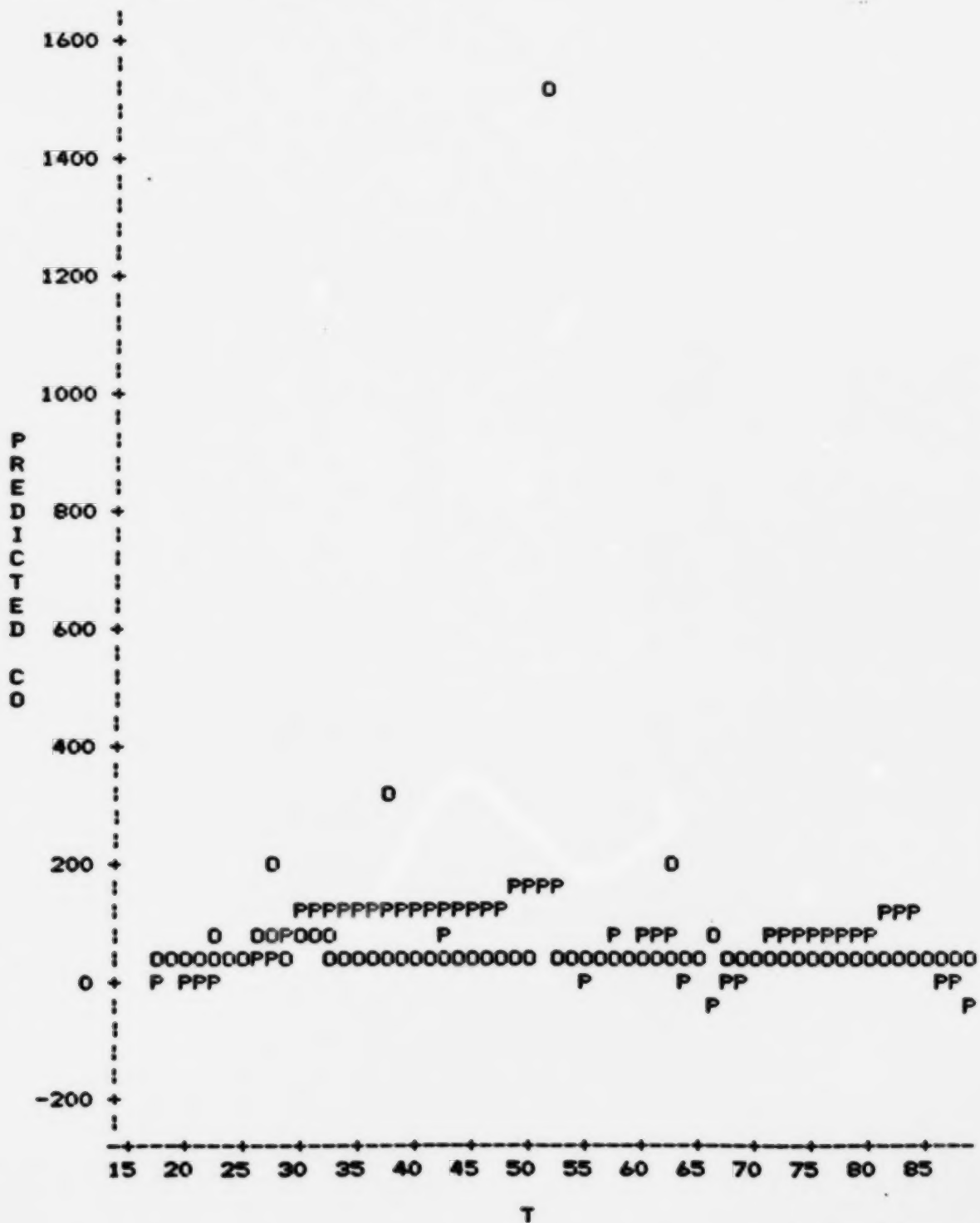


FIGURE 6.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.

O = OBSERVED, P = PREDICTED.

PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF CO2*T SYMBOL USED IS O
PLOT OF PCO2*T SYMBOL USED IS P

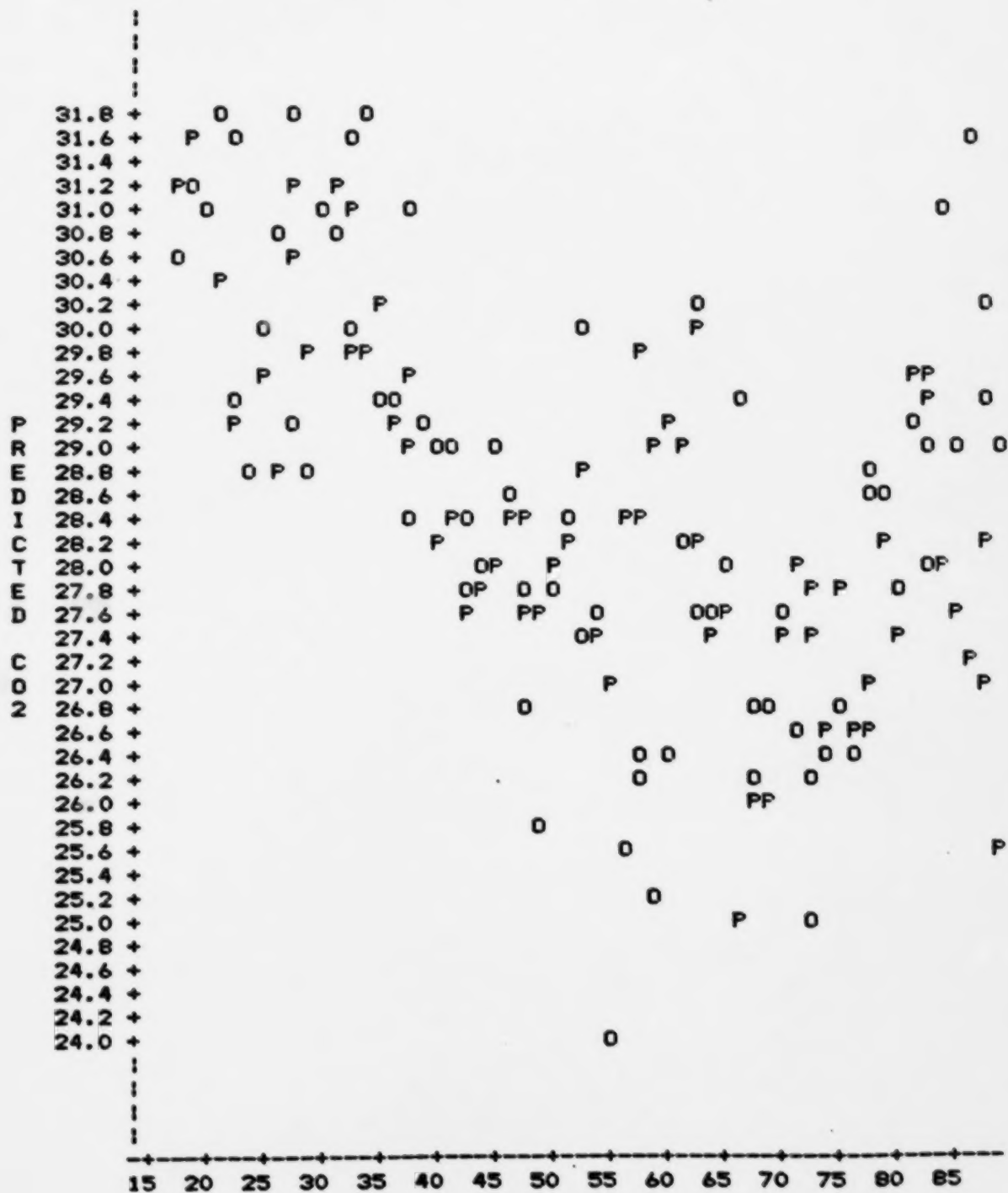


FIGURE 7.
ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF NO*T SYMBOL USED IS O
PLOT OF PNO*T SYMBOL USED IS P

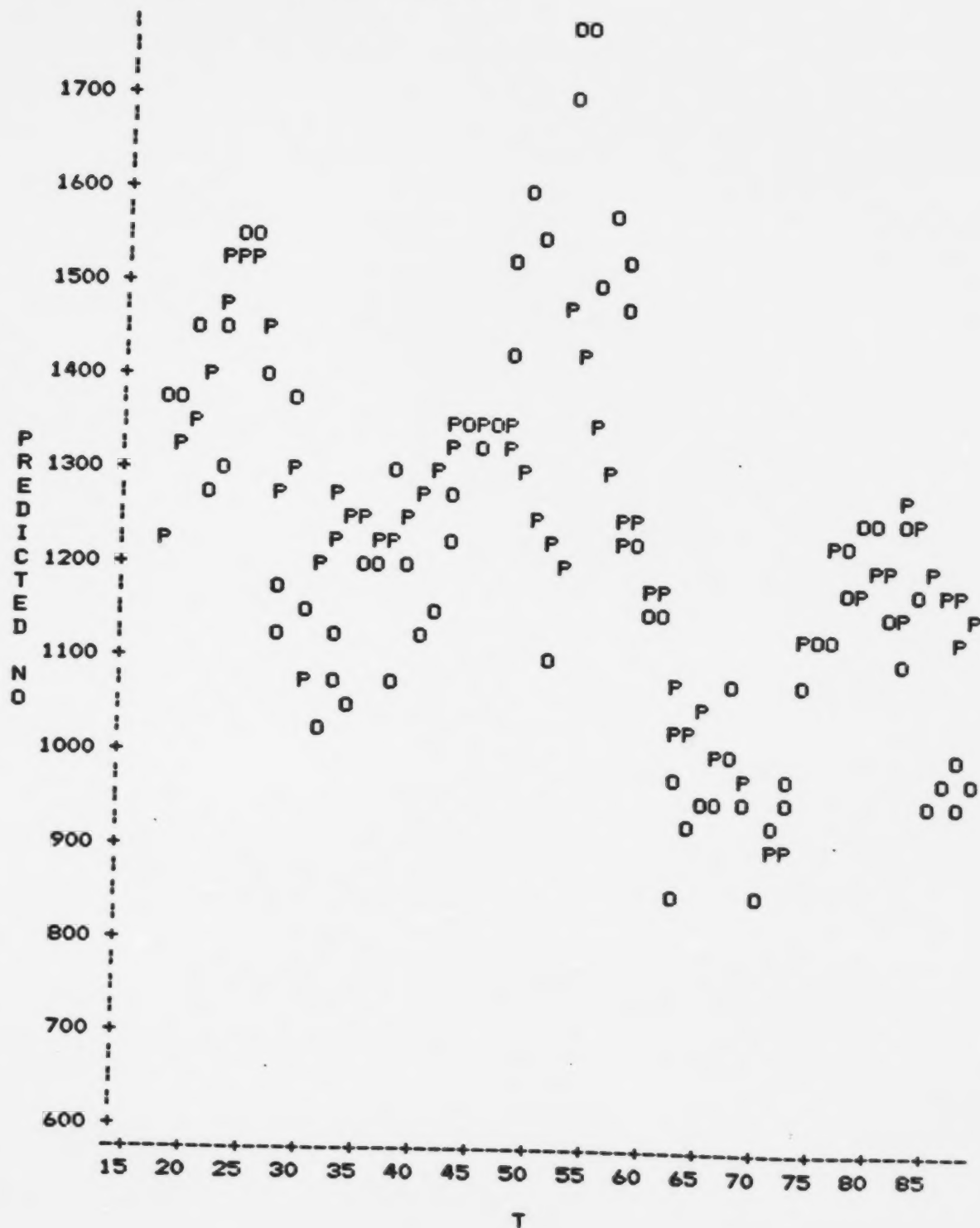


FIGURE 8.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES ARE FORECAST FOR T > 15.

PLOT OF O2*T SYMBOL USED IS O
PLOT OF P02*T SYMBOL USED IS P

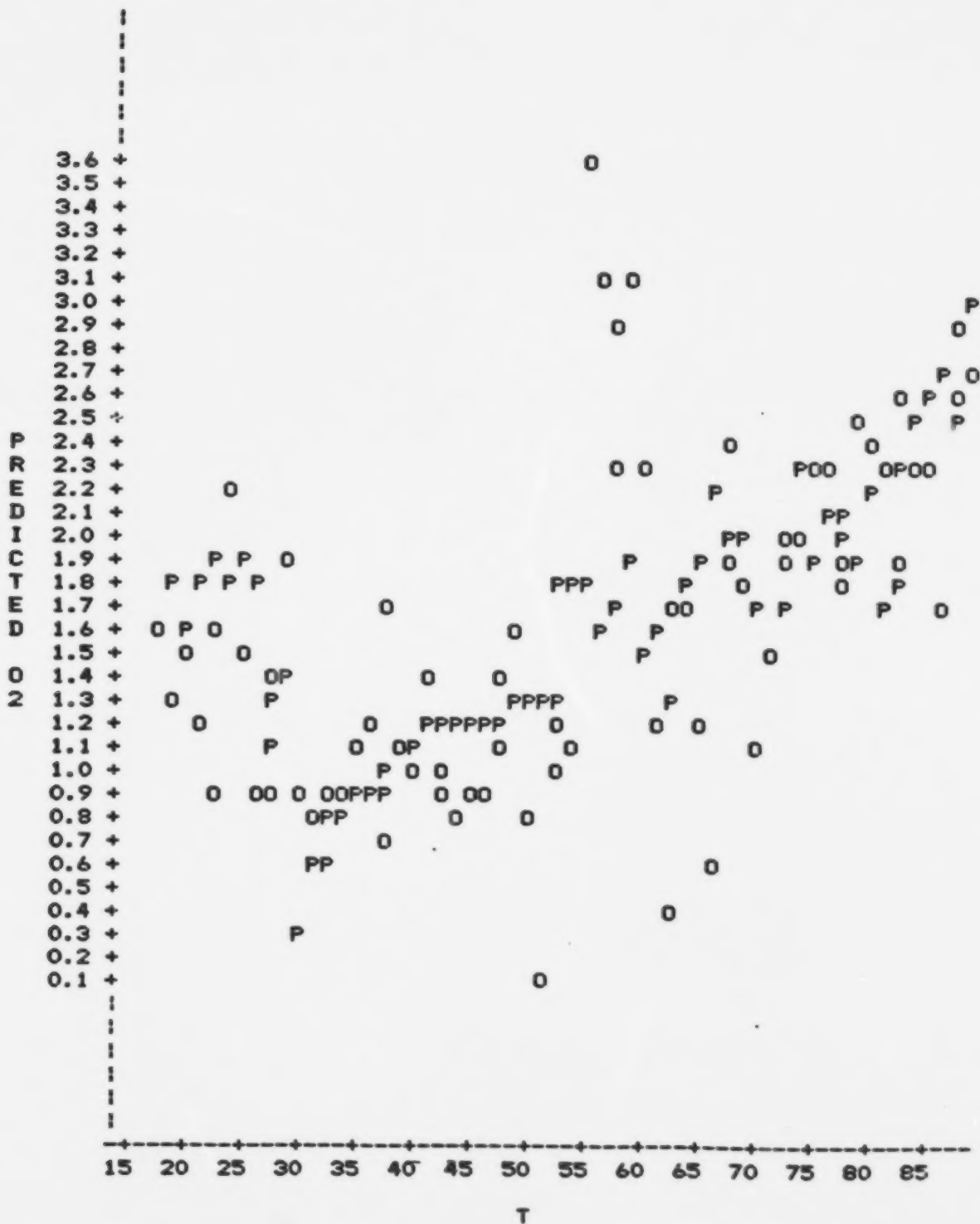


FIGURE 9.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR T > 15.

PLOT OF ROTAT*T SYMBOL USED IS O
 PLOT OF PROTAT*T SYMBOL USED IS P

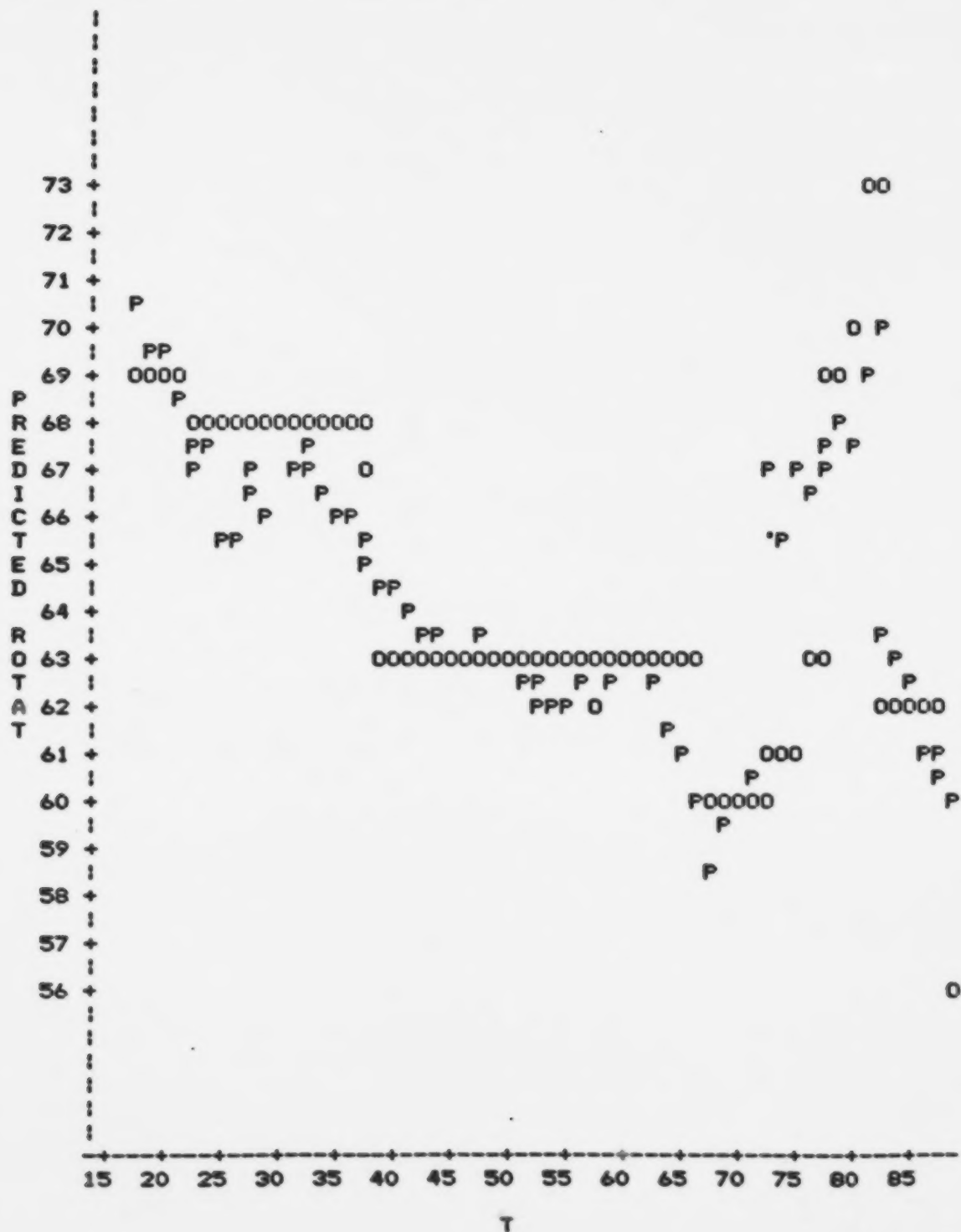


FIGURE 10.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF TEMP*T SYMBOL USED IS O
 PLOT OF PTEMP*T SYMBOL USED IS P

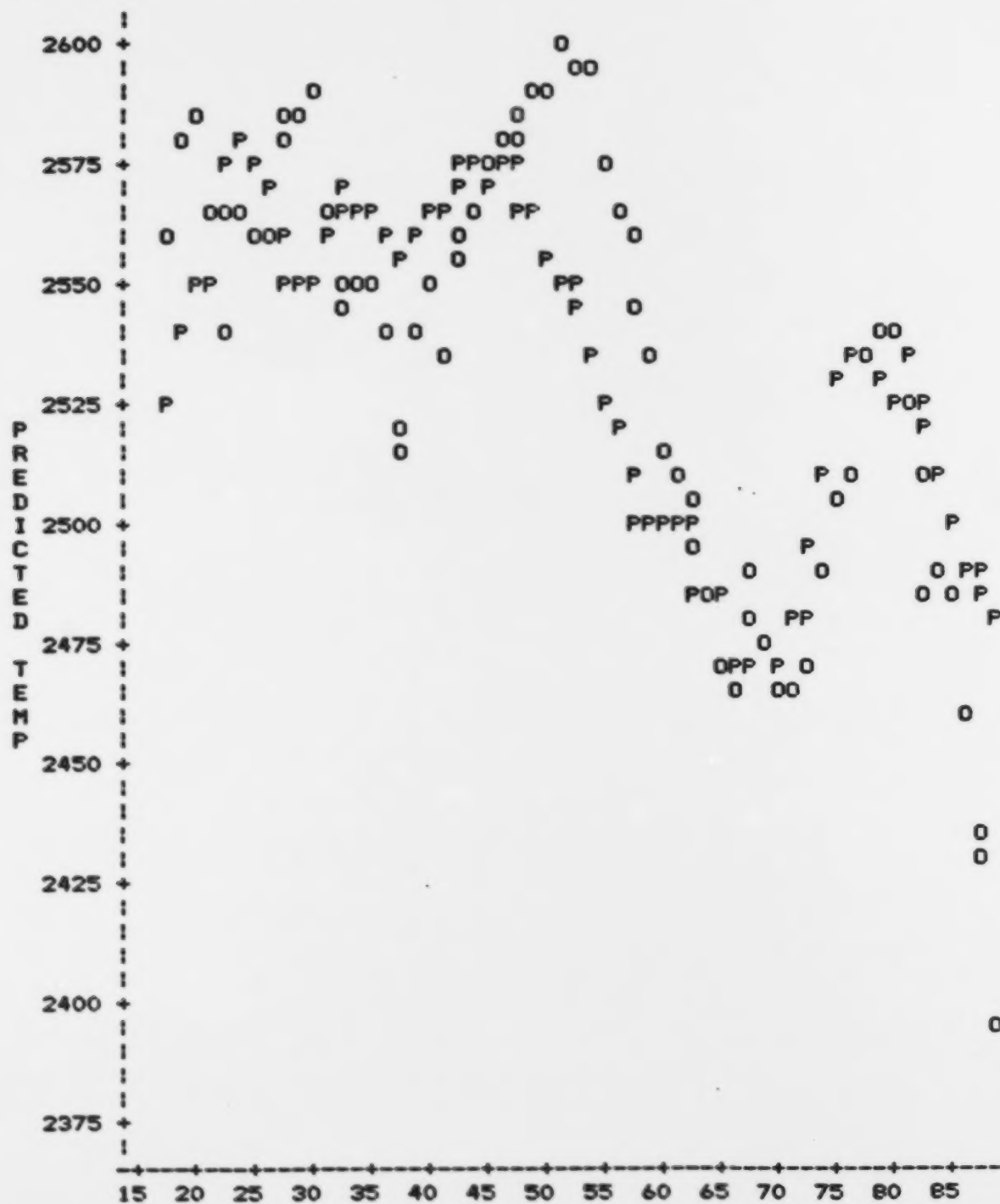


FIGURE 11.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF CO*T
 PLOT OF PCO*T

SYMBOL USED IS O
 SYMBOL USED IS P

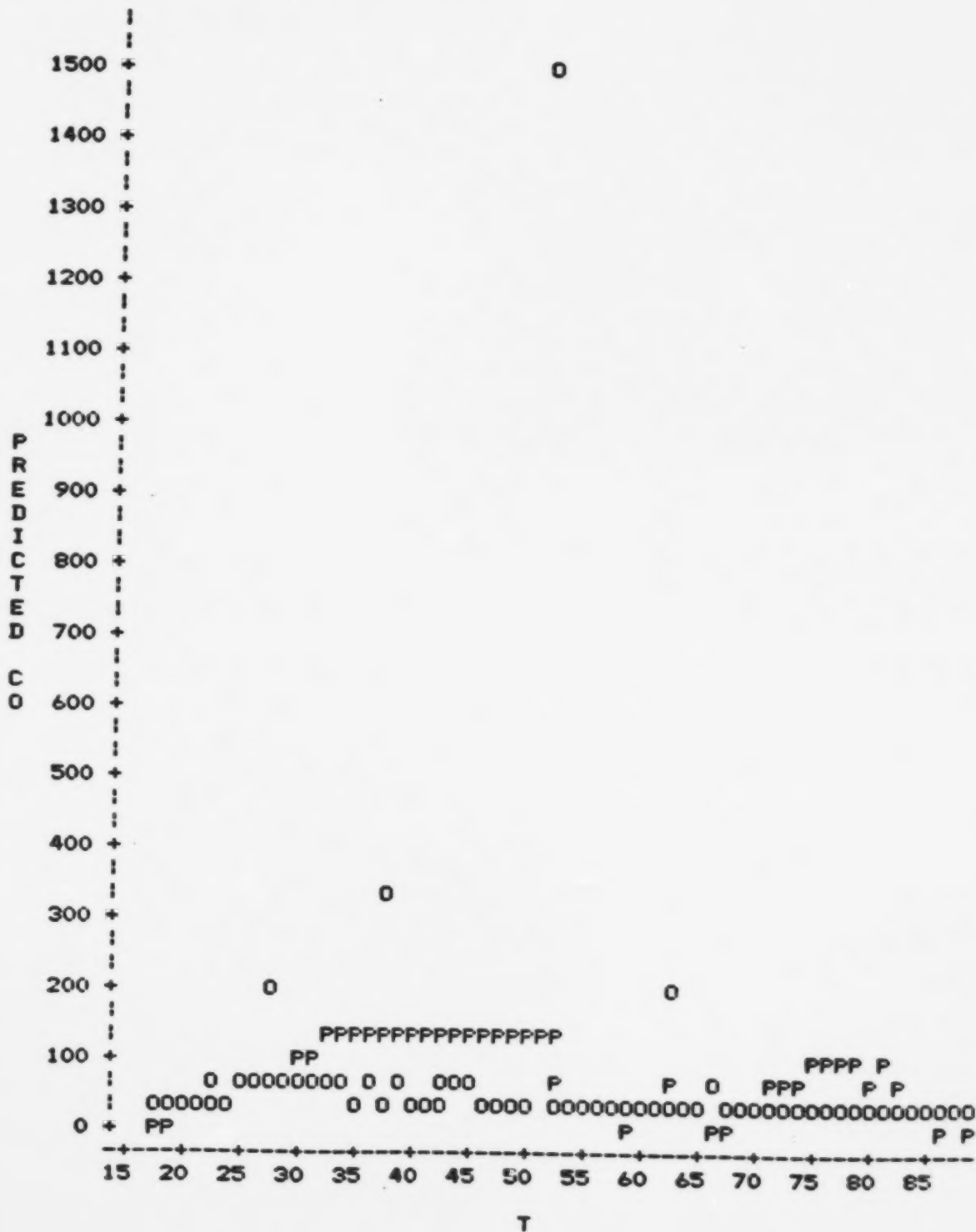


FIGURE 12.

ANALYSIS OF KVB4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES ARE FORECAST FOR T > 15.

PLOT OF CO2*T SYMBOL USED IS O
PLOT OF PCO2*T SYMBOL USED IS P

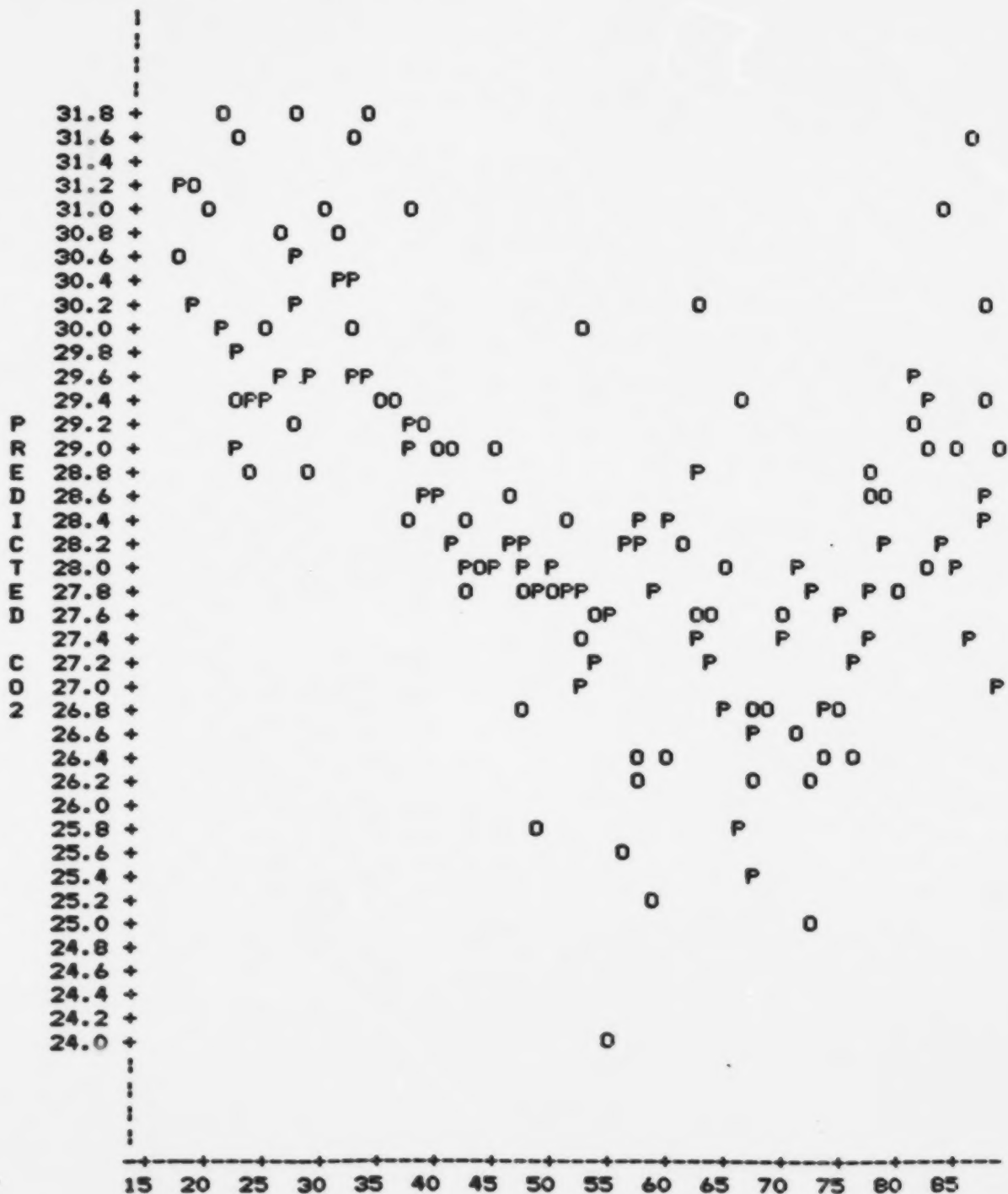


FIGURE 13.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF NO*T SYMBOL USED IS O
 PLOT OF PNO*T SYMBOL USED IS P

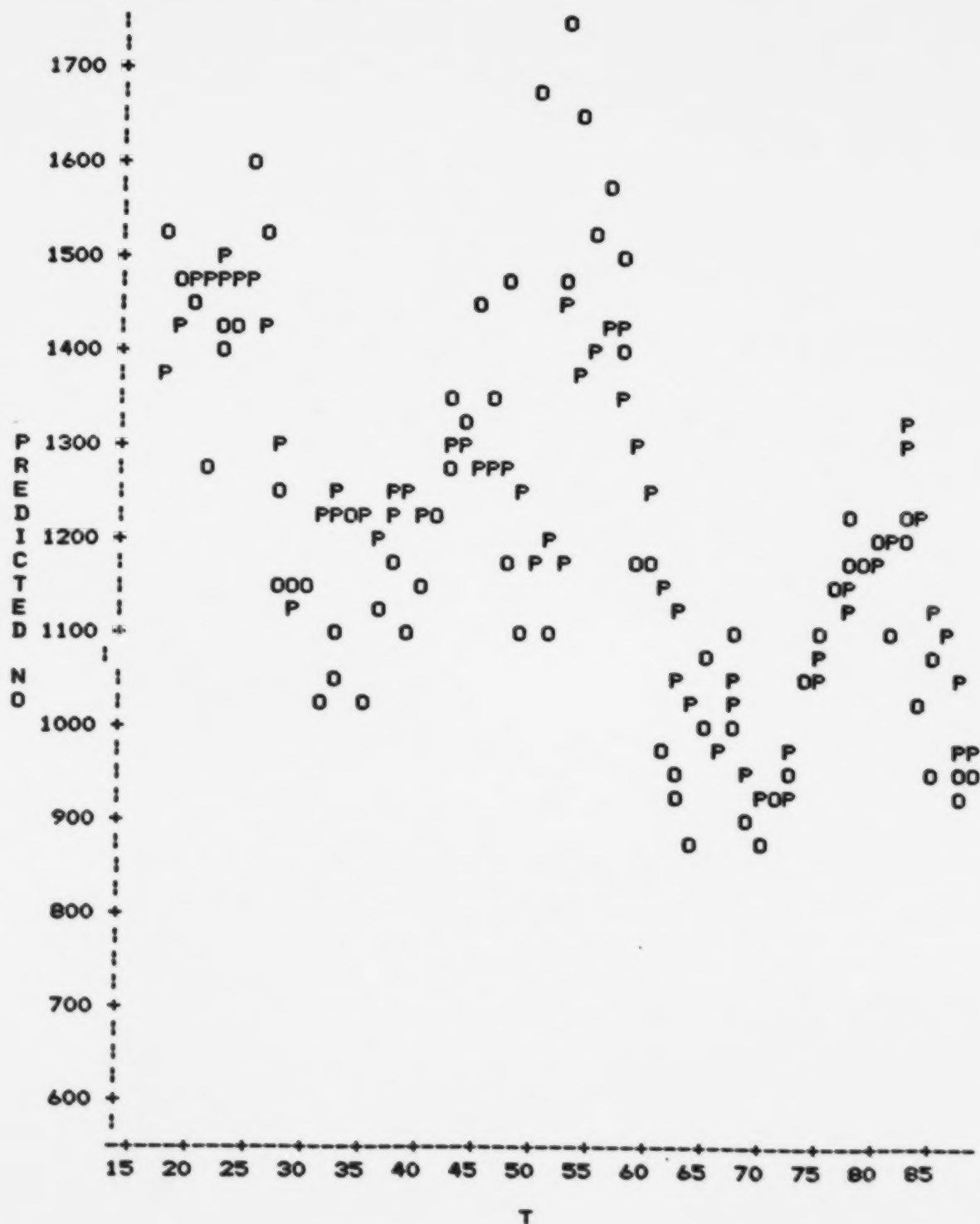


FIGURE 14.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF O2*T SYMBOL USED IS O
PLOT OF P02*T SYMBOL USED IS P

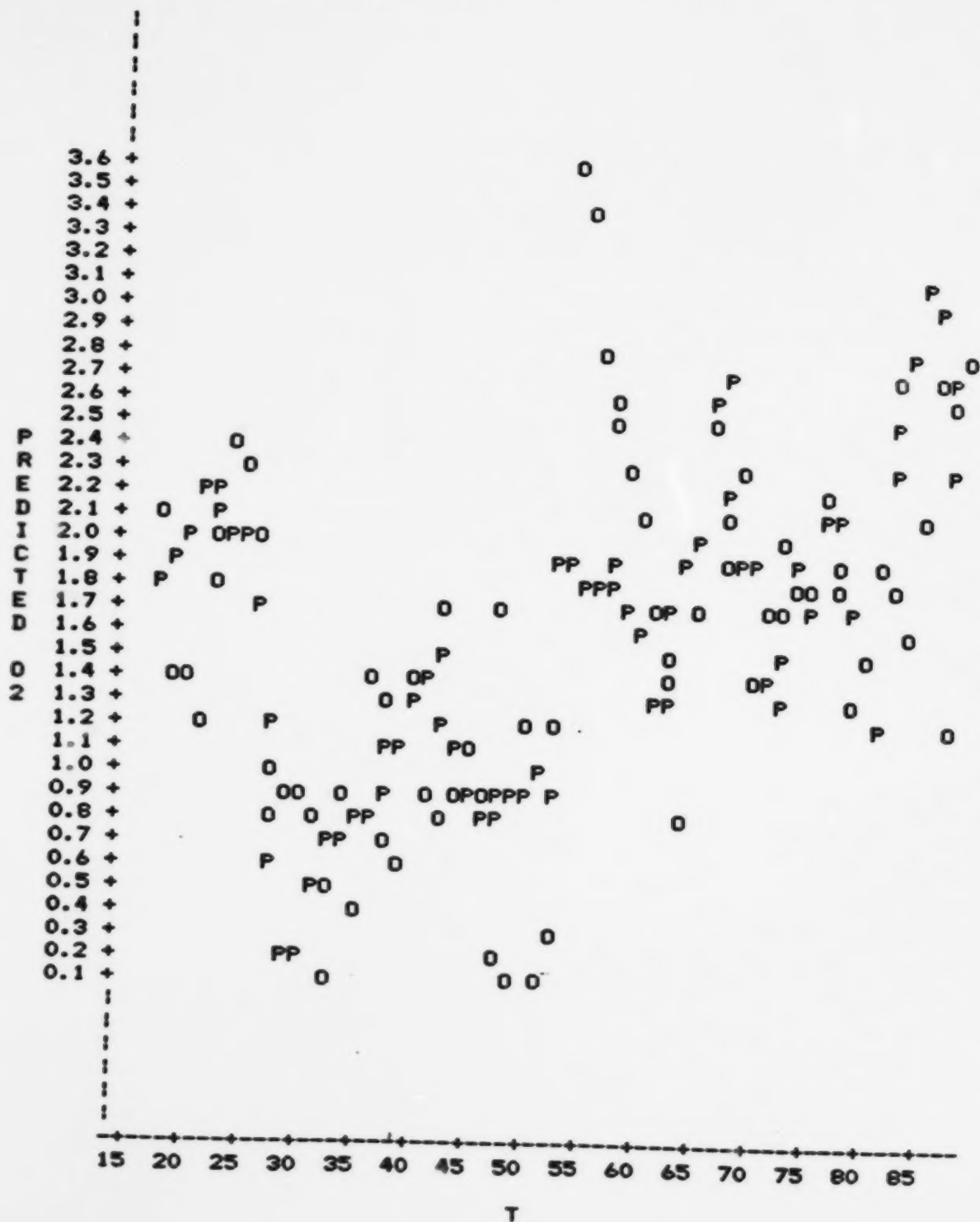


FIGURE 15.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF ROTAT*T
PLOT OF PROTAT*T

SYMBOL USED IS O
SYMBOL USED IS P

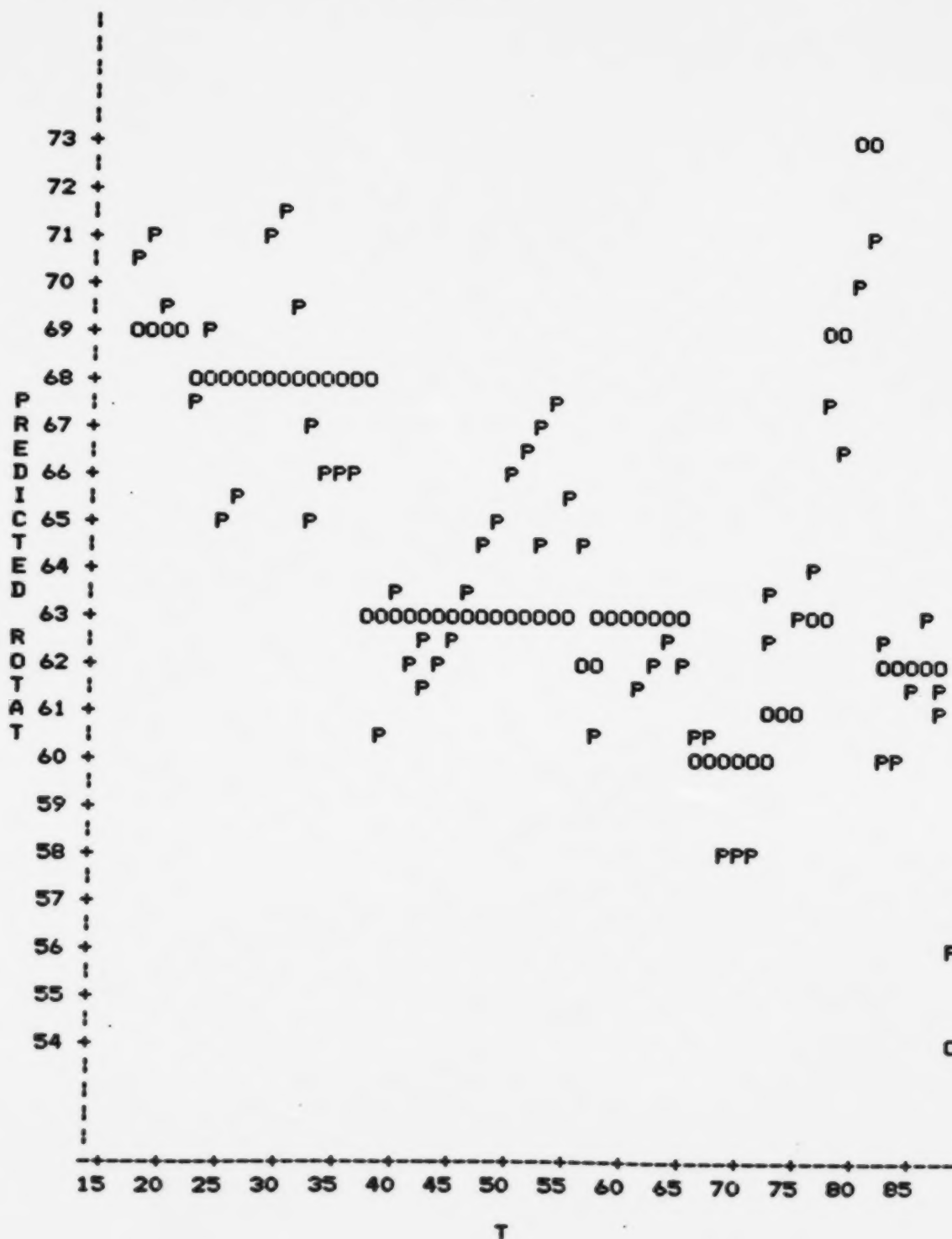


FIGURE 16.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF TEMP*T SYMBOL USED IS O
PLOT OF PTEMP*T SYMBOL USED IS P

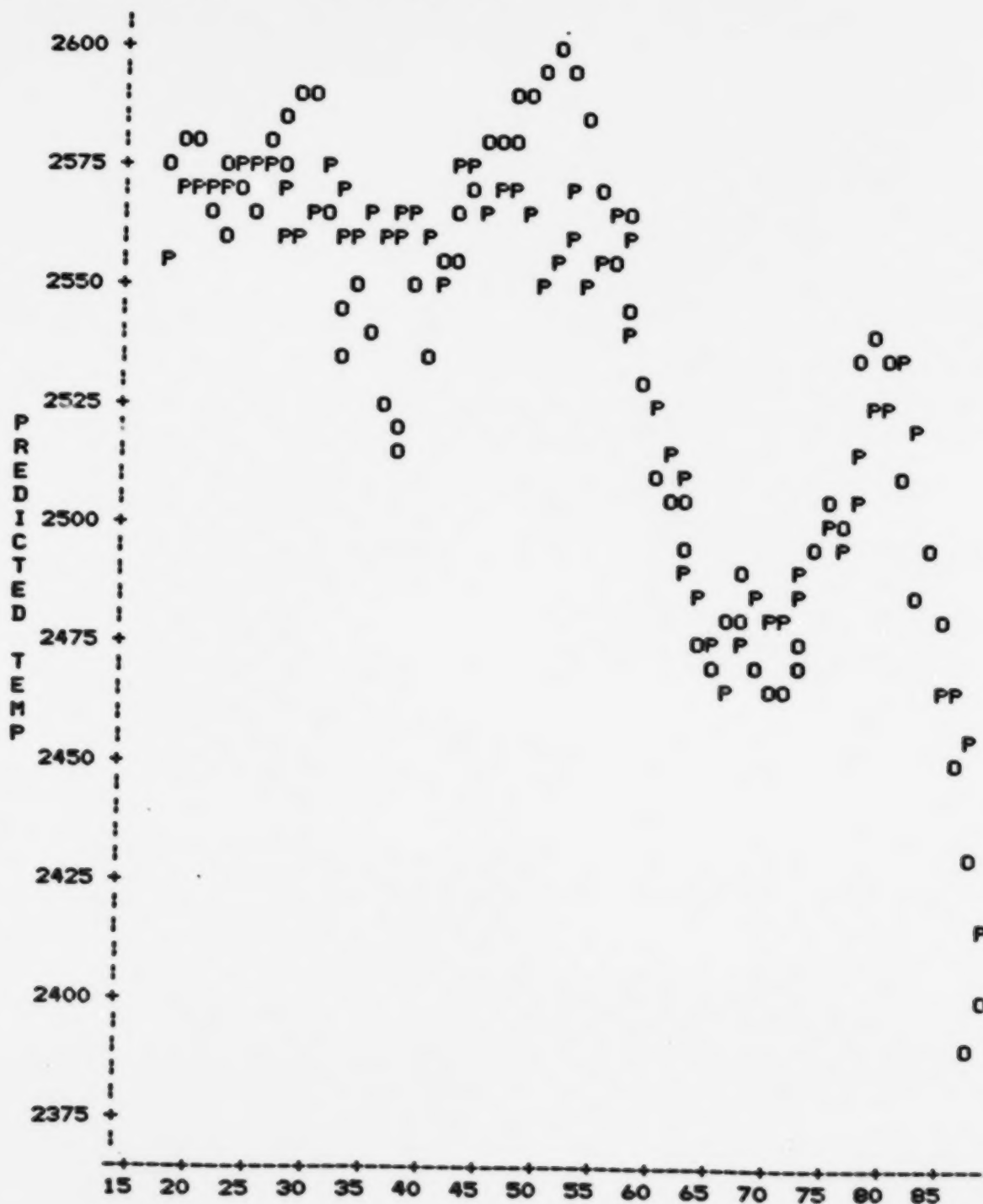


FIGURE 17.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF CO*T SYMBOL USED IS O
 PLOT OF PCO*T SYMBOL USED IS P

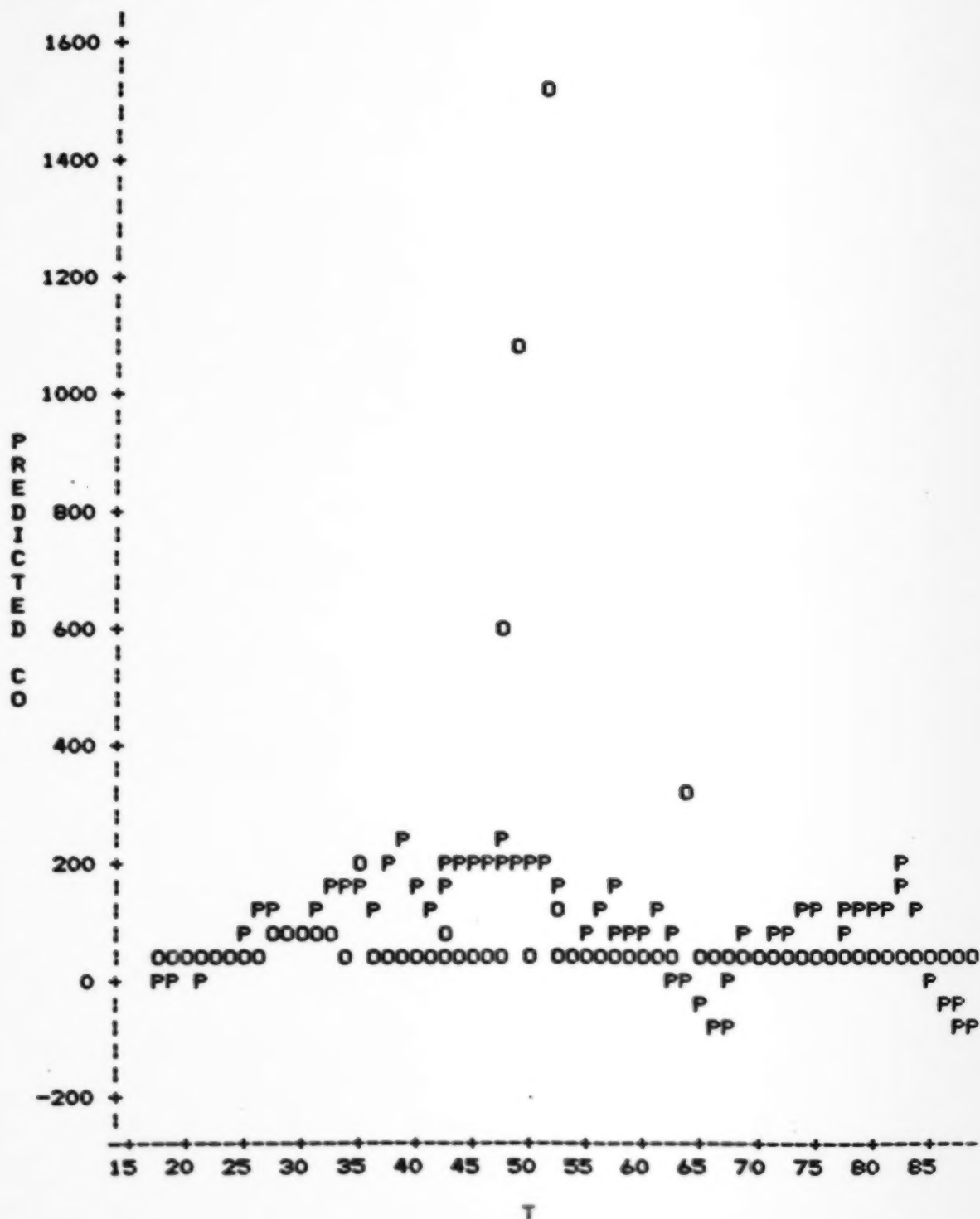


FIGURE 18.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED. P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT OBSERVED ENDOGENOUS VARIABLES.

PLOT OF CO2*T SYMBOL USED IS O
 PLOT OF PCO2*T SYMBOL USED IS P



FIGURE 19.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF NO*T SYMBOL USED IS O
 PLOT OF PNO*T SYMBOL USED IS P

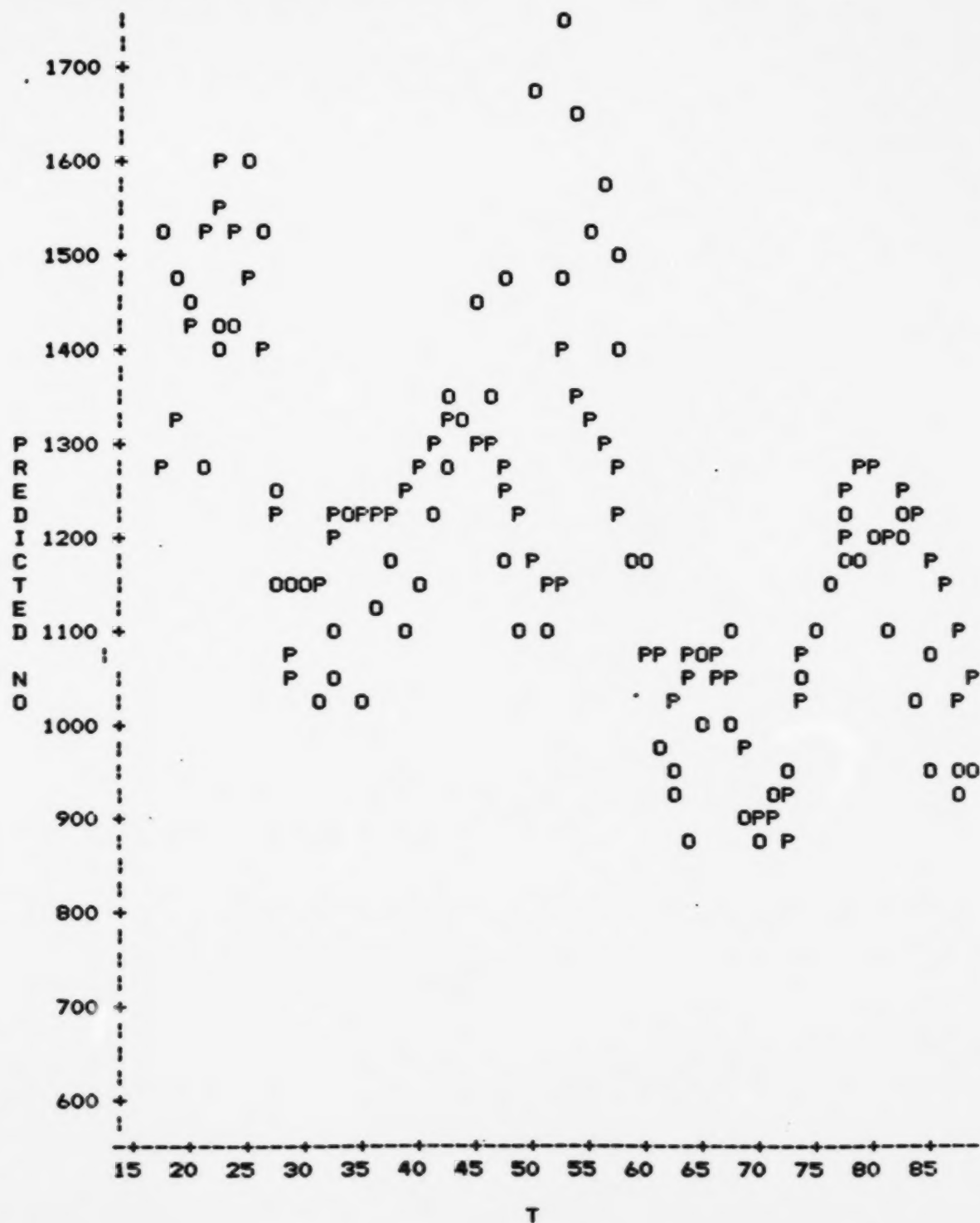


FIGURE 20.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.

O = OBSERVED, P = PREDICTED.

PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $O_2 \cdot T$ SYMBOL USED IS O
PLOT OF $PO_2 \cdot T$ SYMBOL USED IS P

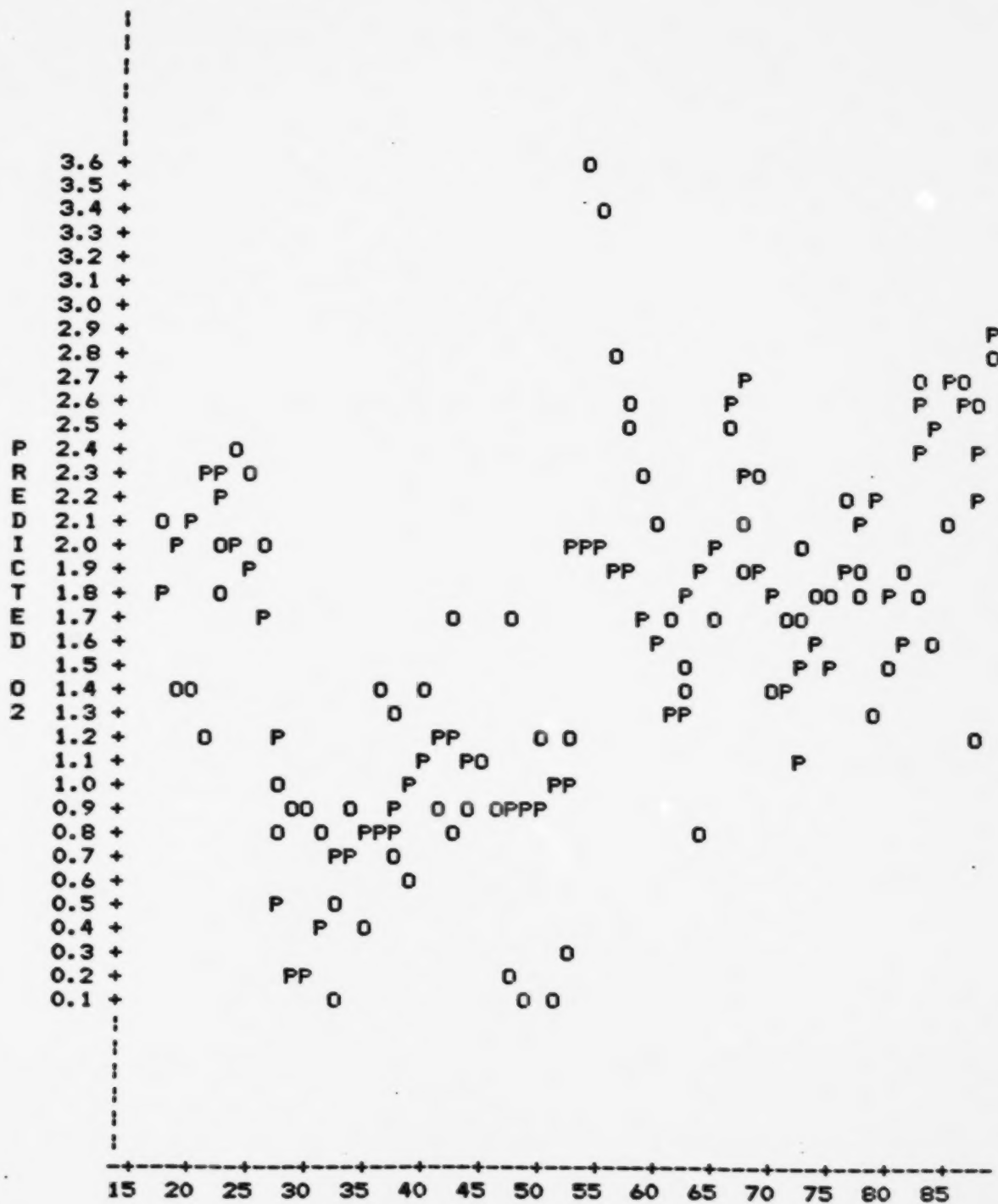


FIGURE 21.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF ROTAT*T SYMBOL USED IS O
 PLOT OF PROTAT*T SYMBOL USED IS P

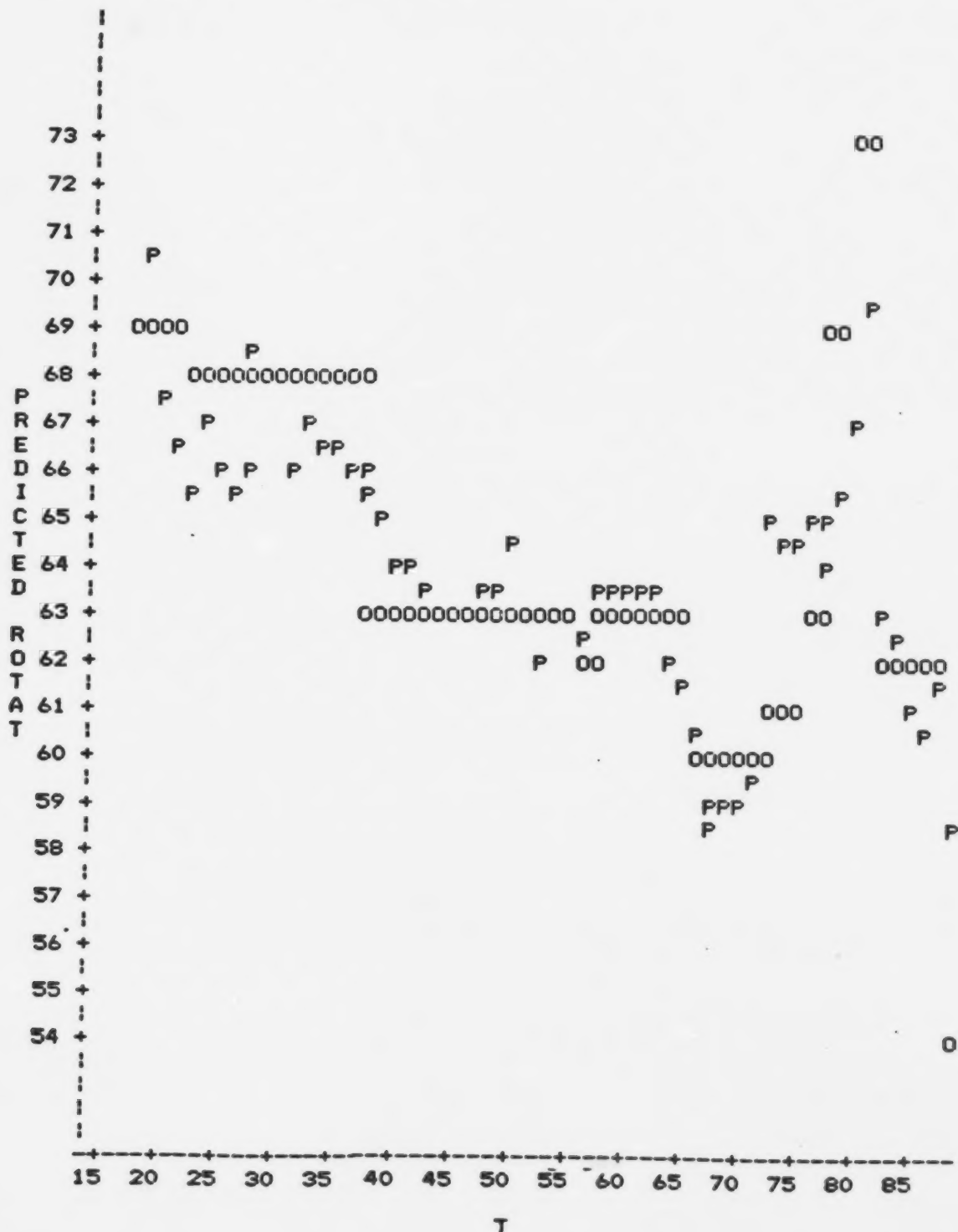


FIGURE 22.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.

O = OBSERVED, P = PREDICTED.

PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF TEMP*T SYMBOL USED IS O
PLOT OF PTEMP*T SYMBOL USED IS P

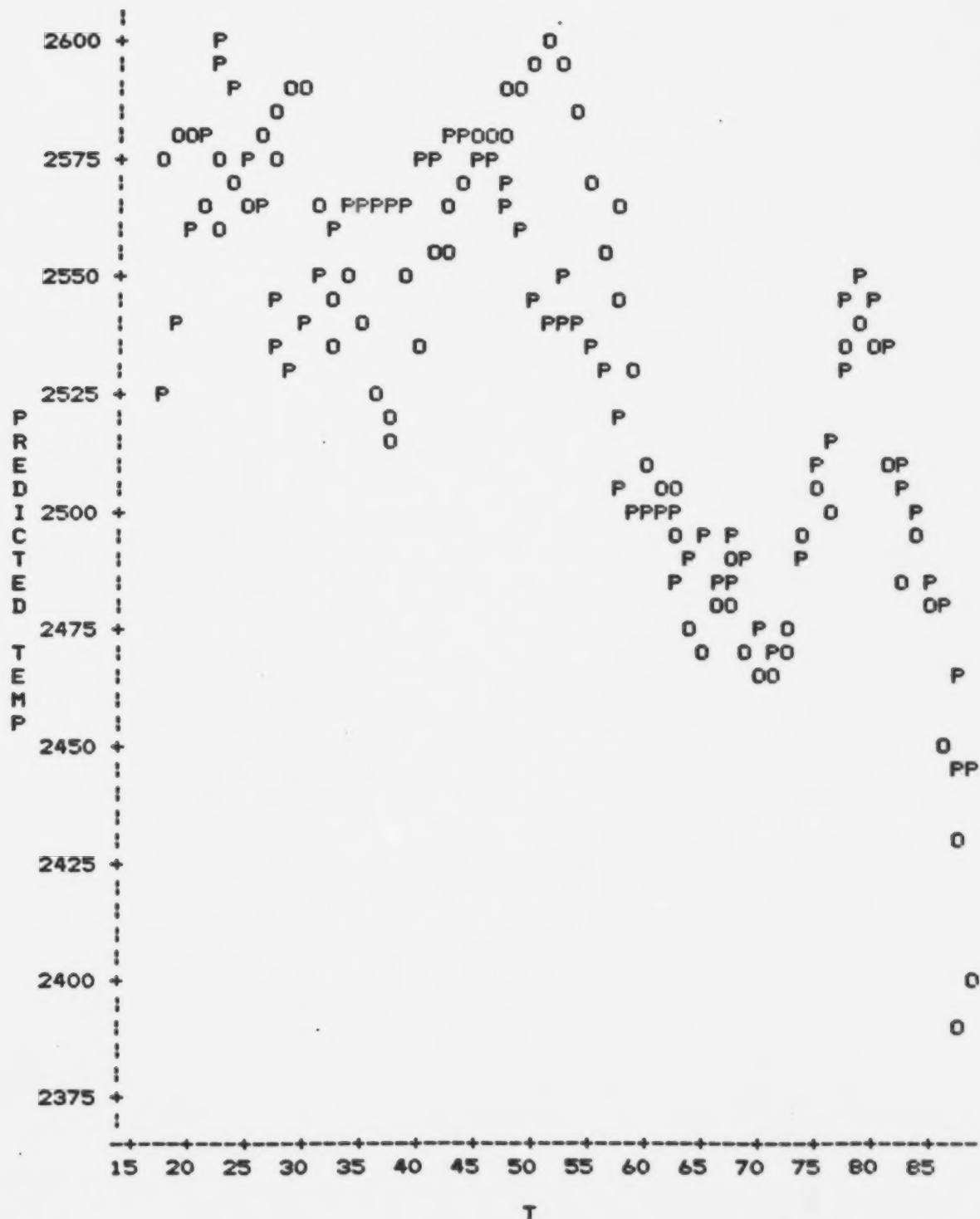


FIGURE 23.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $CO \cdot T$ SYMBOL USED IS O
 PLOT OF $PCO \cdot T$ SYMBOL USED IS P

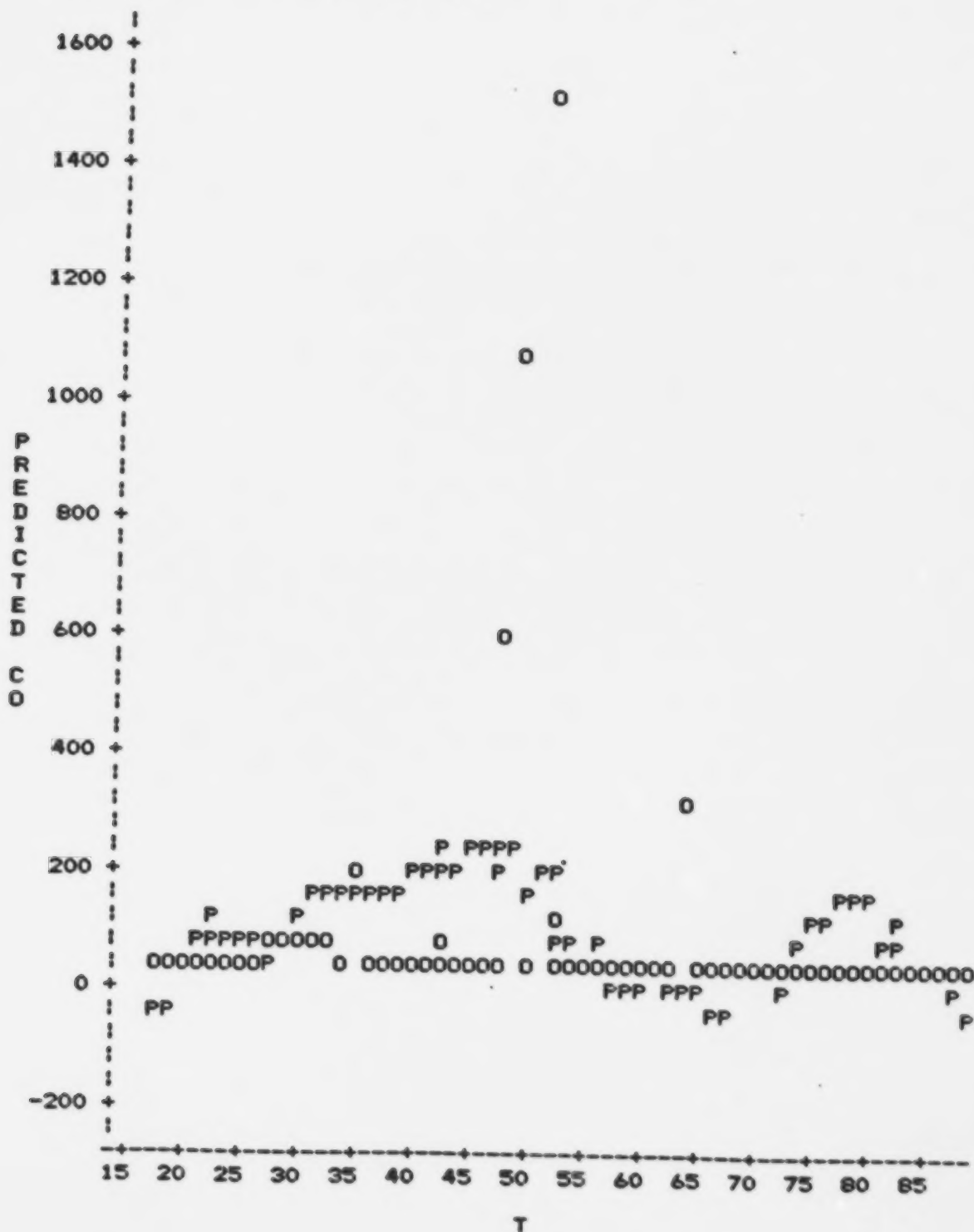


FIGURE 24.

ANALYSIS OF KVB4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $CO_2 \cdot T$ SYMBOL USED IS O
 PLOT OF $PCO_2 \cdot T$ SYMBOL USED IS P



observed (O) and forecasted (P) values are given as Figures 25 - 36. Clearly from $R^2 = 0.8575$ and the plots, the NO model remains quite adequate. Also the TEMP model. The O2 model suffers considerably due to the lack of the MAH1 moving average involving hood pressure. Even though R^2 has increased from 0.6942 to 0.7603, its forecasting ability seems to demonstrate a 'hunting' tendency. This is also true of the CO2 model, even though R^2 is quite high (0.8628). The CO model exhibits the usual deficiencies.

Following our telephone conversation of 1-14-85, I attempted several variations of the foregoing models. Table 9 shows the effect of adding O2 to the KVB4-17 model for NO when applied to the KVB10-5 data. The suggested conclusion is that if TEMP, MAA, and ROTAT are held constant, then O2 and NO seem to be independent ($P = 0.3777$). (MILLO2 and COAL also were held constant here.)

DAMP (air damper) was introduced into the NOC, NO, and O2 models, as shown in Tables 10 and 11 for the KVB4-17 data. Clearly, DAMP had no significant effect on NOC or NO ($P = 0.3083$ and 0.8616 for $\text{Mod}(6) = 2$, and $P = 0.3371$ and 0.5051 for $\text{Mod}(6) = 4$), but did have a significant effect on O2 ($P = 0.0005$ and 0.0397 respectively). Since little or no change occurred in the rest of the structural equation estimates as a result of these modifications, compared to Tables 2 and 4, their estimates are not reproduced here.

Finally, O2 replaced DAMP in the NOC and NO models with DAMP retained in the O2 model, and the results are reported in Tables 12 - 15. NO was retained in the ROTAT model as before. Tables 12 and 14 give estimates of the structural equations for the KVB4-17 $\text{Mod}(6) = 2$ and $\text{Mod}(6) = 4$ data subsets, while Tables 13 and 15 show the effects of relaxing one variable at a time. Note that I have combined the NOC and NO models within the same tables. Generally, the effect of O2 is more significant in the NOC models than in the NO models. MILLO2 remains very significant, except when COAL is allowed to vary. Quite often the effect of ROTAT becomes nonsignificant when O2 is held constant in the NOC and NO models.

I am sure that you can glean other conclusions from this collection of tables and figures, and I encourage you to do so. I haven't intended in this report to list all possible important results (quite likely I wouldn't be able to recognize their importance), but rather to give some assistance in interpreting the results as given by the structural equations approach.

TABLE 8.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL STRUCTURAL EQUATIONS.

MODEL: A	SSE	1066375	F RATIO	106.29
	DFE	53	APPROX PR>F	0.0001
DEP VAR: NO	MSE	20120.28	R-SQUARE	0.8575
	OBJ	1159331		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-12845.3	5275.768	-2.4348	0.0183
B001.TEMP	1	3.186425	0.445751	7.1484	0.0001
B001.MAA	1	14.155849	17.586830	0.8049	0.4245
B001.ROTAT	1	20.295058	8.720877	2.3272	0.0238

MODEL: B	SSE	6.739488	F RATIO	9.86
	DFE	52	APPROX PR>F	0.0001
DEP VAR: O2	MSE	0.129606	R-SQUARE	0.4313
	OBJ	6.689715		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	87.747278	16.506718	5.3159	0.0001
B001.MAH	1	0.014734	0.006974912	2.1125	0.0395
B001.MASR	1	1.100636	0.285902	3.8497	0.0003
B001.MAA	1	-0.286689	0.050124	-5.7196	0.0001
B001.CO2	1	-0.257873	0.054686	-4.7155	0.0001

MODEL: D	SSE	190.906775	F RATIO	16.56
	DFE	47	APPROX PR>F	0.0001
DEP VAR: ROTAT	MSE	4.061846	R-SQUARE	0.7603
	OBJ	127.957165		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	662.053105	212.090730	3.1216	0.0031
B001.TEMP	1	-0.000666041	0.013151	-0.0506	0.9598
B001.O2	1	-0.396079	1.061075	-0.3733	0.7106
B001.NO	1	0.005914676	0.002775529	2.1310	0.0383
B001.CO	1	-0.270372	0.155355	-1.7403	0.0883
B001.DTEMP	1	-0.069099	0.021196	-3.2601	0.0021
B001.DCO2	1	0.497800	0.308730	1.6124	0.1136
B001.MAA	1	-1.684411	0.554760	-3.0363	0.0039
B001.MCO2	1	-0.424296	0.158900	-2.6702	0.0104
HOOD	1	-16.253564	19.629030	-0.8280	0.4118

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
STRUCTURAL EQUATIONS.

MODEL: E	SSE	86325.48	F RATIO	32.82
	DFE	50	APPROX PR>F	0.0001
DEP VAR: TEMP	MSE	1726.51	R-SQUARE	0.7975
	OBJ	86773.94		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	1708.291	3833.744	0.4456	0.6578
B001.MAR	1	1.913703	0.636539	3.0064	0.0041
B001.MAA	1	3.541425	8.721192	0.4061	0.6864
B001.MAH	1	2.219994	1.082971	2.0499	0.0456
B001.MAF	1	0.036917	0.422720	0.0873	0.9308
B001.MC02	1	-9.979550	2.123233	-4.7002	0.0001
FLUX	1	-8.175523	49.389719	-0.1655	0.8692

MODEL: G	SSE	487.205388	F RATIO	9.08
	DFE	52	APPROX PR>F	0.0001
DEP VAR: CO	MSE	9.369334	R-SQUARE	0.4113
	OBJ	547.348891		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	48.212410	20.101222	2.3985	0.0201
B001.TEMP	1	0.003043117	0.00756123	0.4025	0.6890
B001.ROTAT	1	-0.534410	0.191220	-2.7947	0.0073
B001.02	1	-3.329596	1.412865	-2.3566	0.0222
B001.MAF	1	-0.031876	0.026014	-1.2254	0.2260

MODEL: H	SSE	23.576579	F RATIO	52.40
	DFE	50	APPROX PR>F	0.0001
DEP VAR: CO2	MSE	0.471532	R-SQUARE	0.8628
	OBJ	27.316642		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	189.428056	92.125822	2.0562	0.0450
B001.MAF	1	0.028461	0.007289049	3.9046	0.0003
B001.MAA	1	-0.569869	0.205179	-2.7774	0.0077
FLUX	1	0.786908	1.059699	0.7426	0.4612
B001.MAR	1	-0.011366	0.013279	-0.8559	0.3961
B001.02	1	-0.276207	0.518143	-0.5331	0.5963
B001.DC02	1	0.470309	0.112325	4.1870	0.0001

FIGURE 25.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF NO*T SYMBOL USED IS O
 PLOT OF PNO*T SYMBOL USED IS P

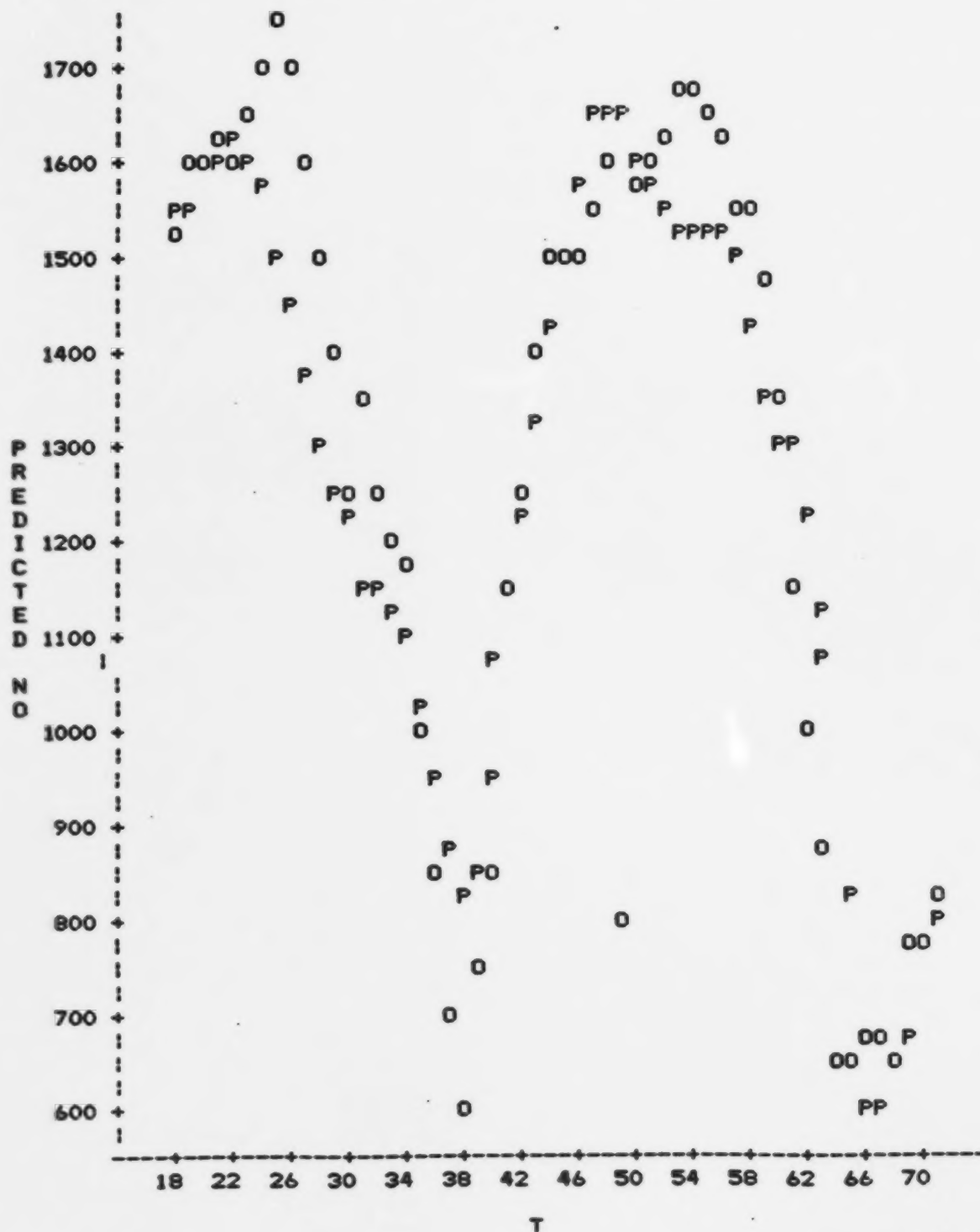


FIGURE 26.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF O2*T
 PLOT OF PO2*T

SYMBOL USED IS O
 SYMBOL USED IS P

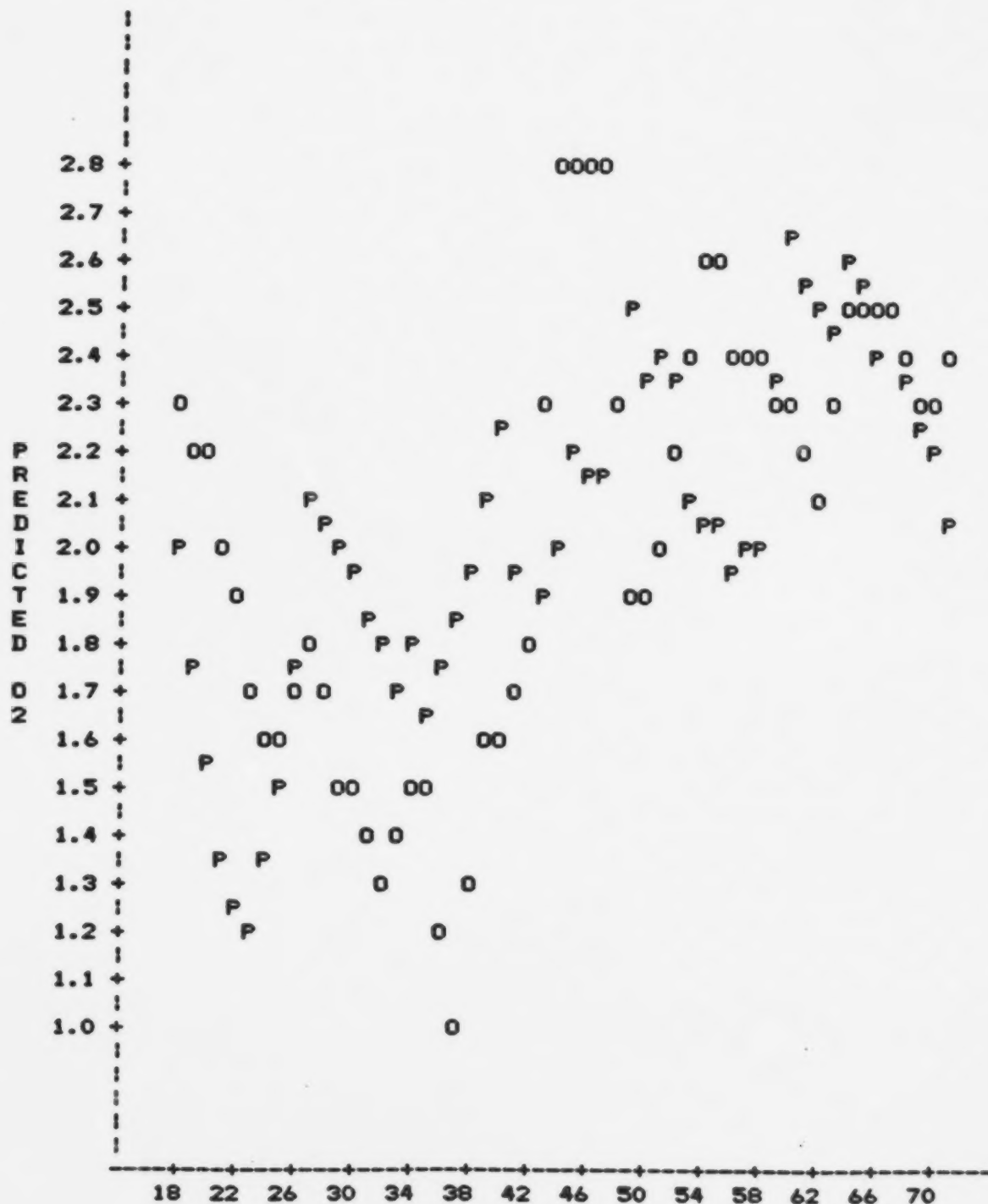


FIGURE 27.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF ROTAT*T SYMBOL USED IS O
 PLOT OF PROTAT*T SYMBOL USED IS P

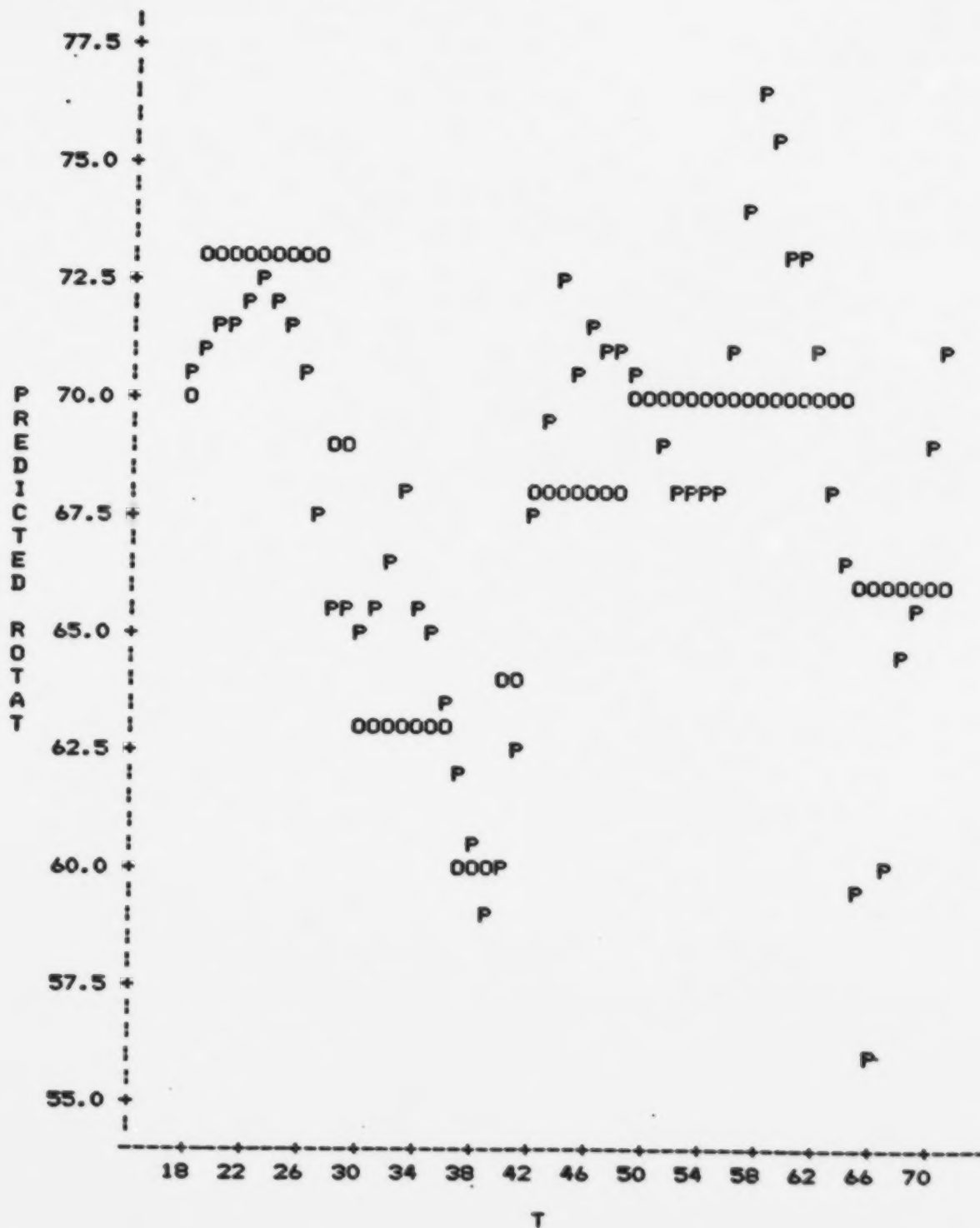


FIGURE 28.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF TEMP*T SYMBOL USED IS O
 PLOT OF PTEMP*T SYMBOL USED IS P

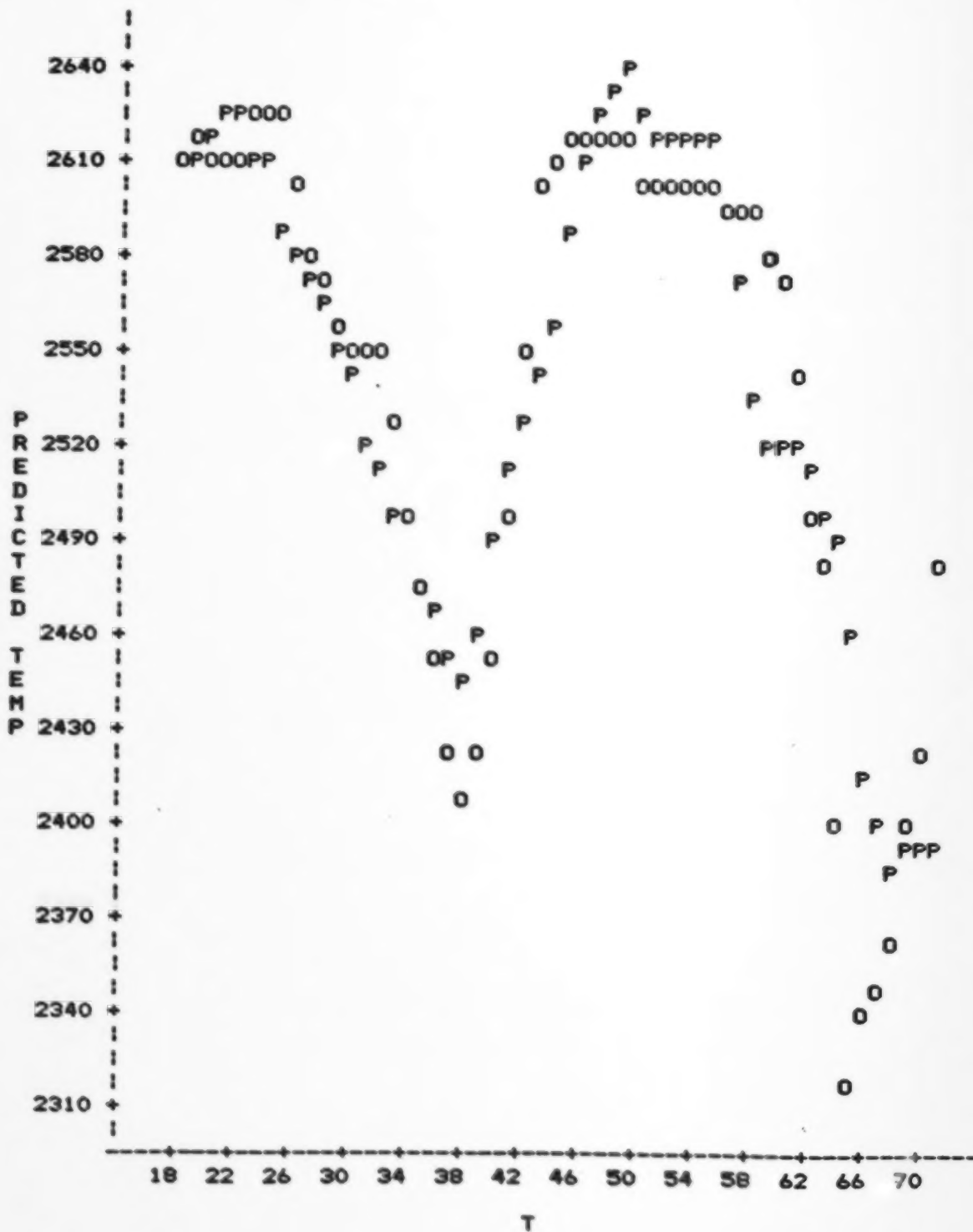


FIGURE 29.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF CO*T
 PLOT OF PCO*T

SYMBOL USED IS O
 SYMBOL USED IS P

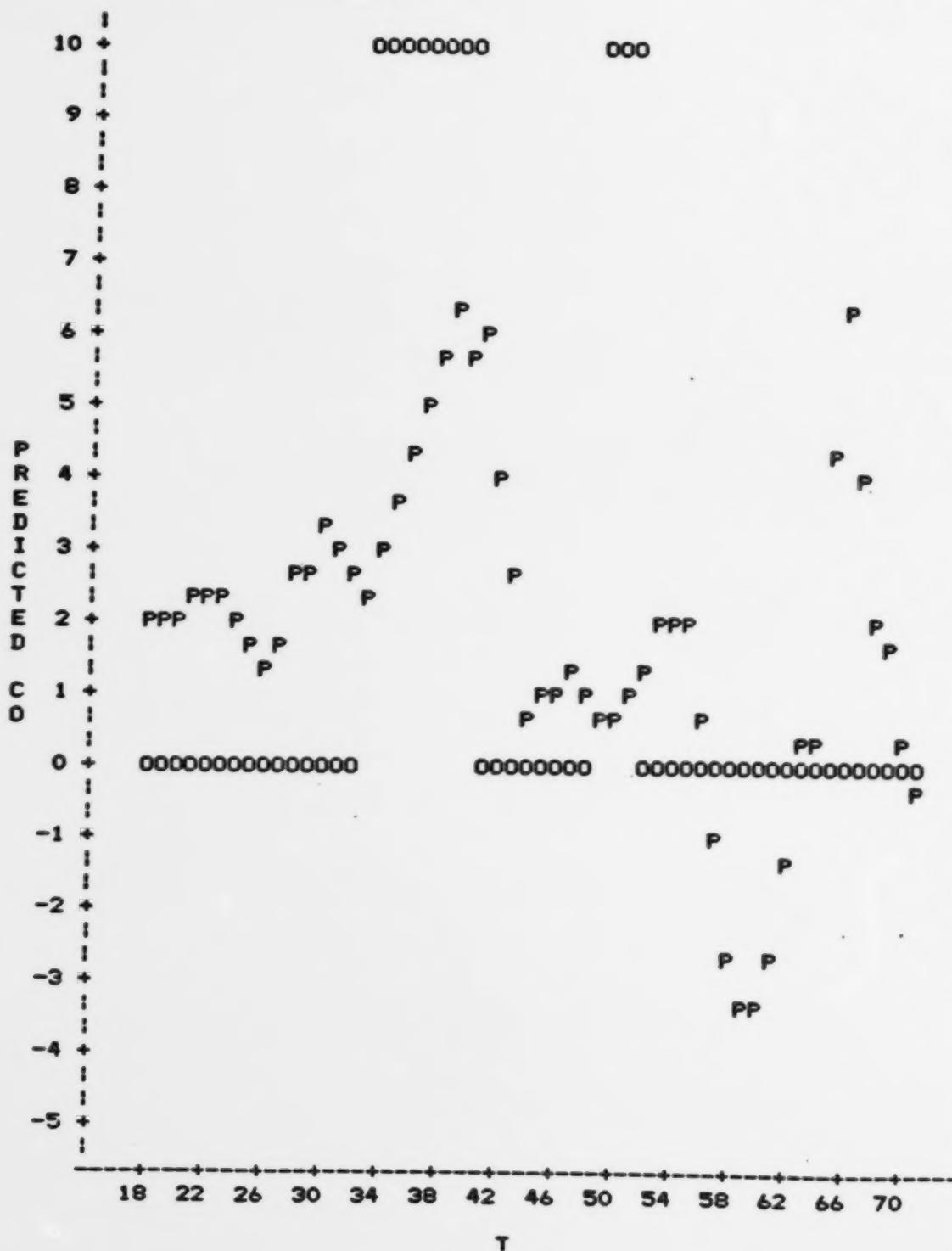


FIGURE 30.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES REFLECT THE CURRENT ENDOGENOUS VARIABLES.

PLOT OF CO2*T
 PLOT OF PCO2*T

SYMBOL USED IS O
 SYMBOL USED IS P

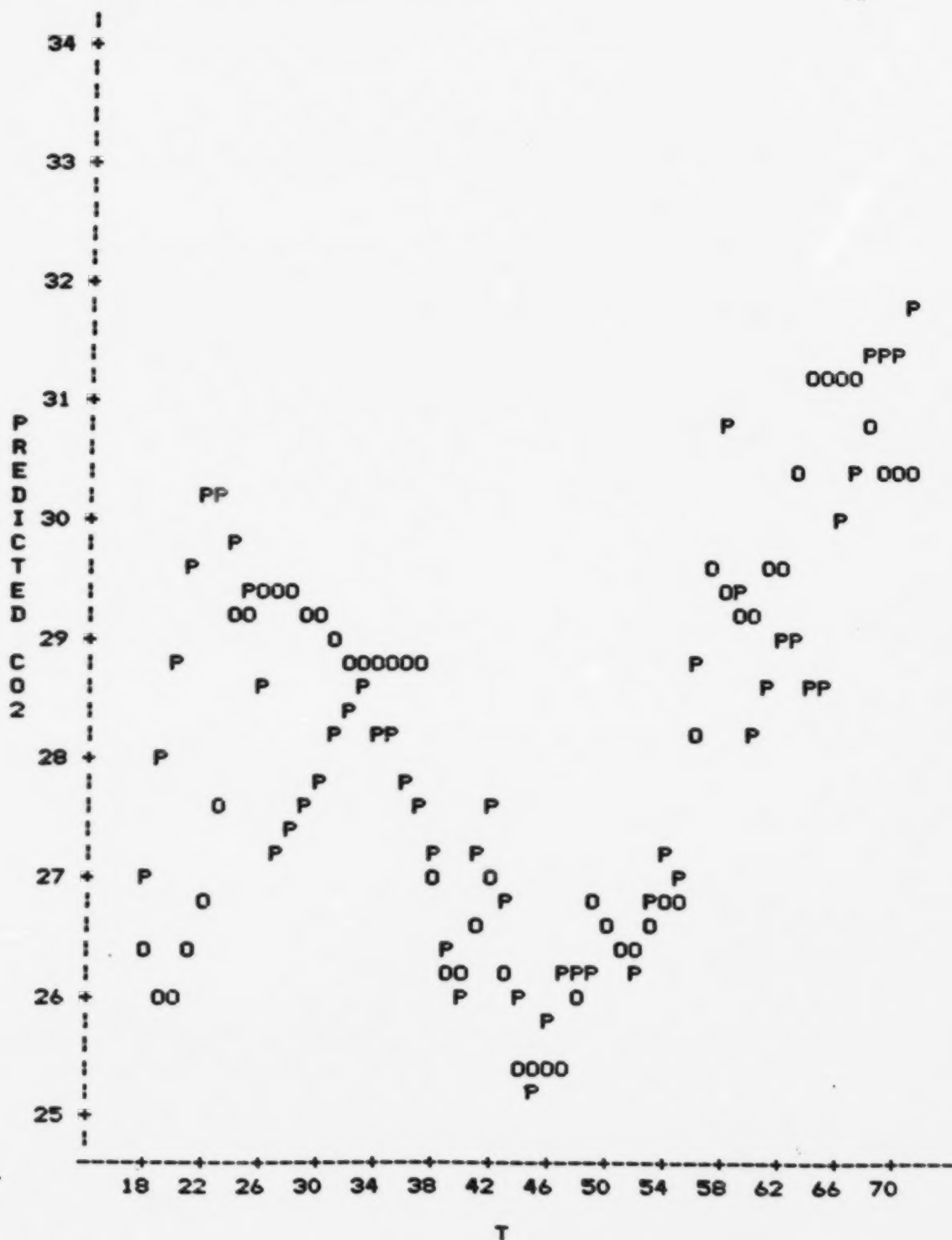


FIGURE 31.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF NO*T
 PLOT OF PNO*T

SYMBOL USED IS O
 SYMBOL USED IS P

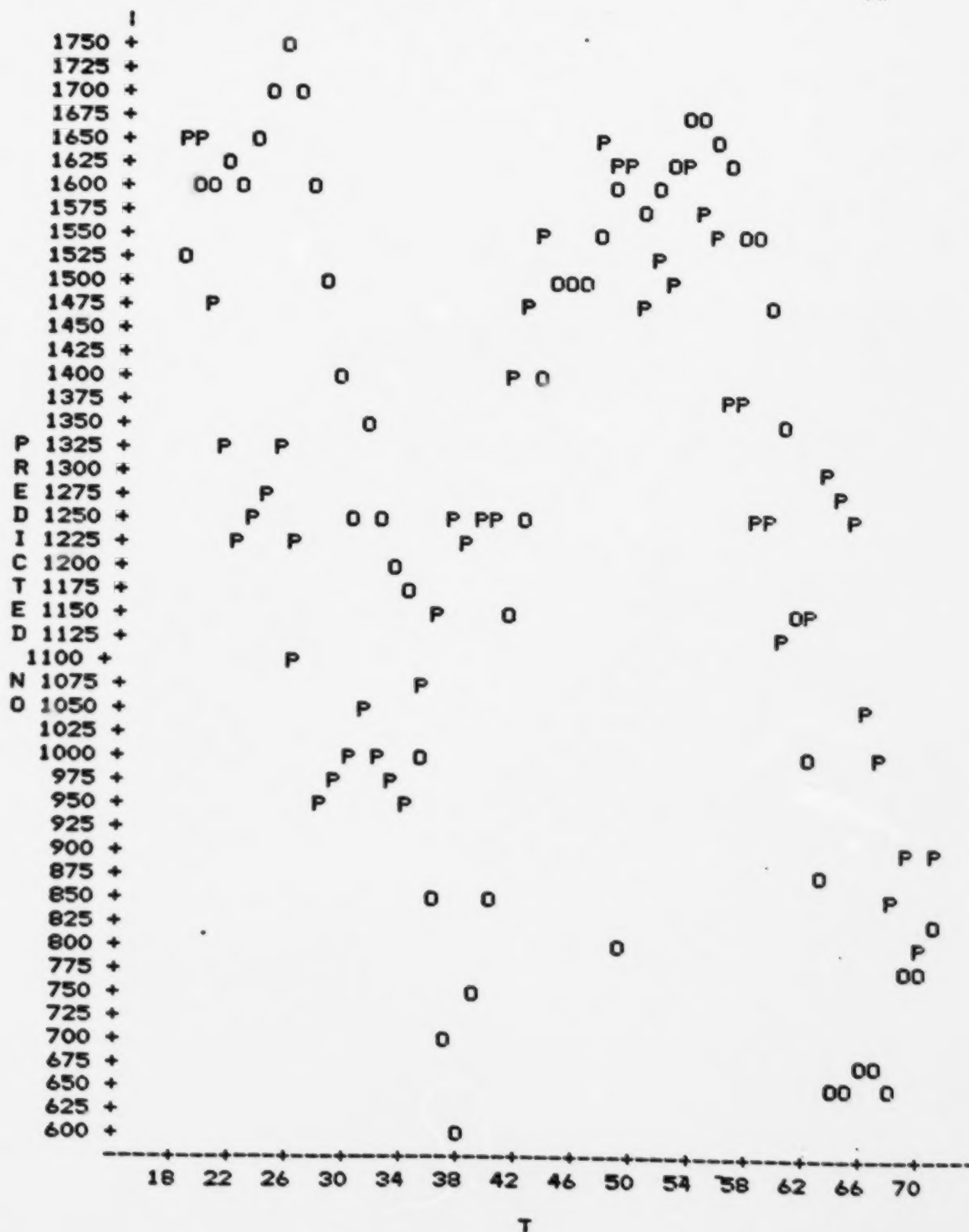


FIGURE 32.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES' AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $O_2 \cdot T$ SYMBOL USED IS O
 PLOT OF $P_{O_2} \cdot T$ SYMBOL USED IS P

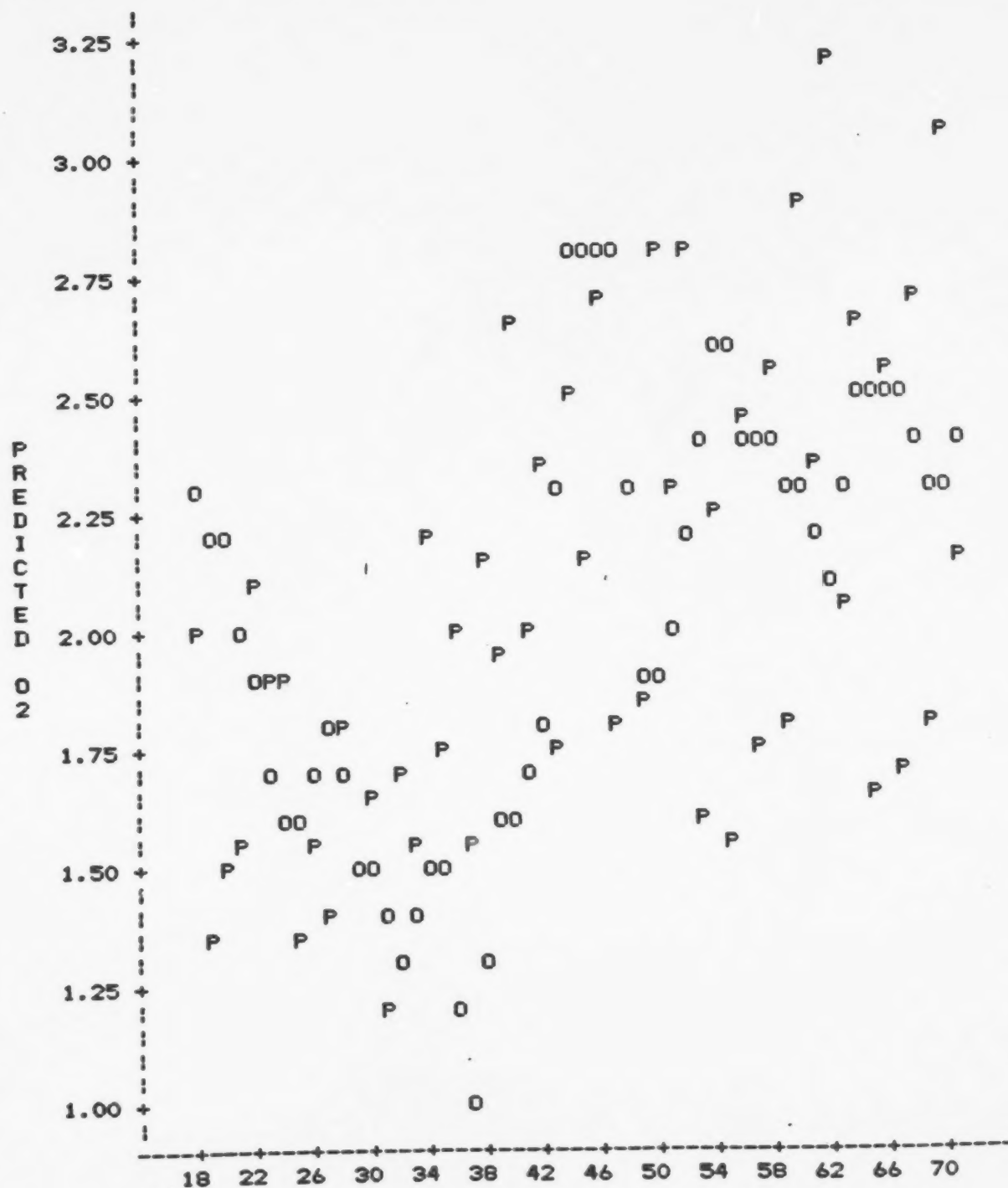
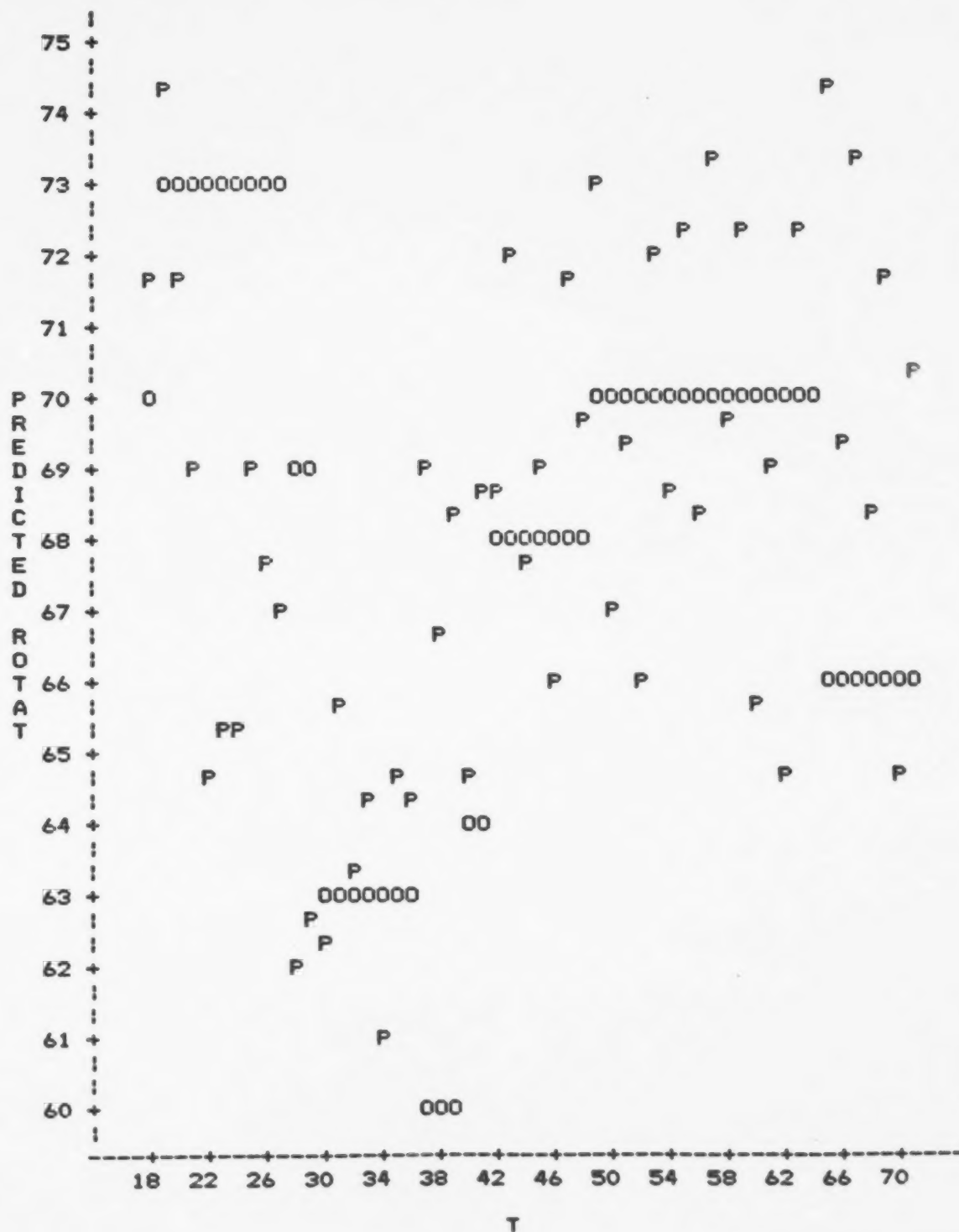


FIGURE 33.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF ROTAT*T SYMBOL USED IS O
 PLOT OF PROTAT*T SYMBOL USED IS P



ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
O = OBSERVED, P = PREDICTED.
PREDICTED VALUES ARE FORECAST FOR T > 15.

Predicted Temperature (°C) vs. Time (h)

Time (h)	Predicted Temperature (°C)	Observed Temperature (°C)
18	2610	
22	2610	
26	2610	
30	2610	
34	2610	
38	2610	
42	2610	
46	2610	
50	2610	
54	2610	
58	2610	
62	2610	
66	2610	
70	2610	
18	2580	
22	2580	
26	2580	
30	2580	
34	2580	
38	2580	
42	2580	
46	2580	
50	2580	
54	2580	
58	2580	
62	2580	
66	2580	
70	2580	
18	2550	
22	2550	
26	2550	
30	2550	
34	2550	
38	2550	
42	2550	
46	2550	
50	2550	
54	2550	
58	2550	
62	2550	
66	2550	
70	2550	
18	2520	
22	2520	
26	2520	
30	2520	
34	2520	
38	2520	
42	2520	
46	2520	
50	2520	
54	2520	
58	2520	
62	2520	
66	2520	
70	2520	
18	2490	
22	2490	
26	2490	
30	2490	
34	2490	
38	2490	
42	2490	
46	2490	
50	2490	
54	2490	
58	2490	
62	2490	
66	2490	
70	2490	
18	2460	
22	2460	
26	2460	
30	2460	
34	2460	
38	2460	
42	2460	
46	2460	
50	2460	
54	2460	
58	2460	
62	2460	
66	2460	
70	2460	
18	2430	
22	2430	
26	2430	
30	2430	
34	2430	
38	2430	
42	2430	
46	2430	
50	2430	
54	2430	
58	2430	
62	2430	
66	2430	
70	2430	
18	2400	
22	2400	
26	2400	
30	2400	
34	2400	
38	2400	
42	2400	
46	2400	
50	2400	
54	2400	
58	2400	
62	2400	
66	2400	
70	2400	
18	2370	
22	2370	
26	2370	
30	2370	
34	2370	
38	2370	
42	2370	
46	2370	
50	2370	
54	2370	
58	2370	
62	2370	
66	2370	
70	2370	
18	2340	
22	2340	
26	2340	
30	2340	
3		

FIGURE 35.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $CO \cdot T$ SYMBOL USED IS O
 PLOT OF $PCO \cdot T$ SYMBOL USED IS P

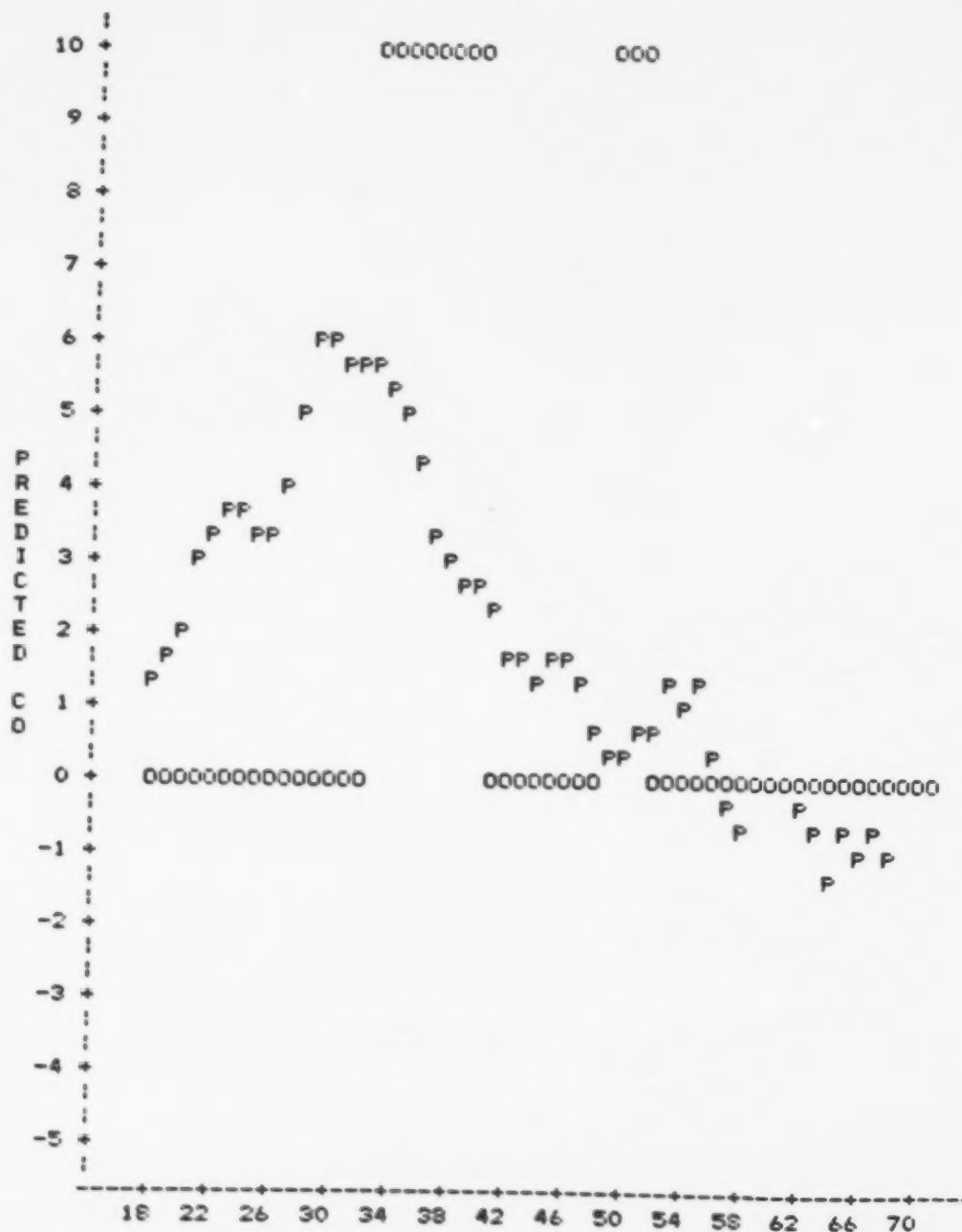


FIGURE 36.

ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
 O = OBSERVED, P = PREDICTED.
 PREDICTED VALUES ARE FORECAST FOR $T > 15$.

PLOT OF $CO_2 \cdot T$ SYMBOL USED IS O
 PLOT OF $PCO_2 \cdot T$ SYMBOL USED IS P

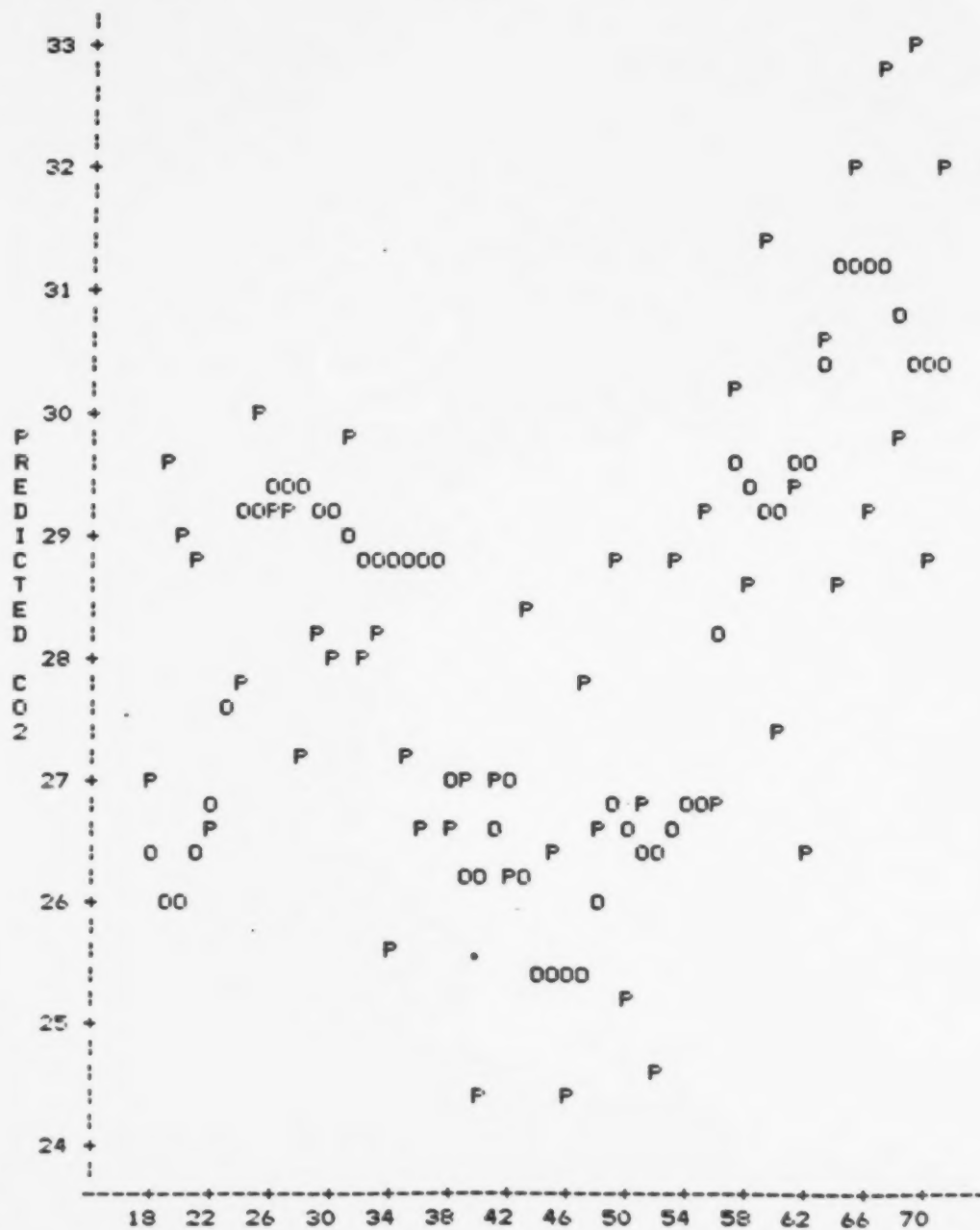


TABLE 9.
ANALYSIS OF KVB10-5 DATA USING TWO STAGE LEAST SQUARES AND KVB4-17 MODEL
EXHAUST O2 HAS BEEN ADDED TO THE NO MODEL.

MODEL: A	SSE	1090425	F RATIO	76.68
DEP VAR: NO	DFE	52	APPROX PR>F	0.0001
	MSE	20969.72	R-SQUARE	0.8550
	OBJ	1142723		

SECOND STAGE STATISTICS				
VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO
INTERCEPT	1	-11584.6	5569.203	-2.0801
B001.TEMP	1	3.204048	0.455494	7.0342
B001.MAA	1	9.924749	18.573243	0.5344
B001.ROTAT	1	23.011359	9.411879	2.4449
B001.O2	1	-49.595666	55.737648	-0.8898

	APPROX PROB> T
INTERCEPT	0.0425
B001.TEMP	0.0001
B001.MAA	0.5954
B001.ROTAT	0.0179
B001.O2	0.3777

TABLE 10.
ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH DAMP ADDED TO THE NO AND O2 MODELS.

MODEL: AA	SSE	1464996	F RATIO	16.90
	DFE	68	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	21544.06	R-SQUARE	0.5986
	OBJ	1551102		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	5698.562	4749.05	1.1999	0.2343
MILLO2	1	42.207726	17.092601	2.4694	0.0161
B001.ROTAT	1	-8.021895	8.062638	-0.9949	0.3233
B001.MAA	1	-13.918142	7.252360	-1.9191	0.0592
B001.TEMP	1	2.807524	0.742862	3.7793	0.0003
COAL	1	-567.803511	140.936192	-4.0288	0.0001
DAMP	1	-24.510425	23.877552	-1.0265	0.3083

MODEL: A	SSE	944325.3	F RATIO	31.04
	DFE	68	APPROX PR>F	0.0001
DEP VAR: NO	MSE	13887.14	R-SQUARE	0.7325
	OBJ	1025414		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	1466.801	3812.846	0.3847	0.7017
MILLO2	1	49.688408	13.723052	3.6208	0.0006
B001.ROTAT	1	-6.388350	6.473210	-0.9869	0.3272
B001.TEMP	1	3.522487	0.596418	5.9061	0.0001
B001.MAA	1	-13.443575	5.822667	-2.3088	0.0240
COAL	1	-521.858523	113.152740	-4.6120	0.0001
DAMP	1	-3.356016	19.170452	-0.1751	0.8616

MODEL: B	SSE	10.308927	F RATIO	20.68
	DFE	67	APPROX PR>F	0.0001
DEP VAR: O2	MSE	0.153865	R-SQUARE	0.6836
	OBJ	16.158016		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	22.267826	8.218084	2.7096	0.0085
B001.MAH	1	0.011082	0.009525842	1.1634	0.2488
B001.MASR	1	-0.367601	0.159695	-2.3019	0.0245
MILLO2	1	0.030470	0.046543	0.6547	0.5149
COAL	1	-0.454144	0.398565	-1.1394	0.2586
B001.MAA	1	0.030531	0.016285	1.8747	0.0652
B001.CO2	1	-0.273805	0.064129	-4.2696	0.0001
DAMP	1	-0.218697	0.059992	-3.6454	0.0005

TABLE 11.
ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH DAMP ADDED TO THE NO AND O2 MODELS.

MODEL: AA	SSE	1196098	F RATIO	20.65
	DFE	68	APPROX PROB	0.0001
DEF VAR: NOC	MSE	17589.68	R-SQUARE	0.6456
	OBJ	1317932		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	538.919505	4104.797	0.1313	0.8959
MILLO2	1	38.068847	13.456658	2.8290	0.0061
B001.ROTAT	1	-7.107562	6.816792	-1.0427	0.3008
B001.MAA	1	-3.159651	5.807437	-0.5441	0.5882
B001.TEMP	1	3.209963	0.640284	5.0133	0.0001
COAL	1	-542.061719	117.213911	-4.6246	0.0001
DAMP	1	-19.806353	20.487778	-0.9667	0.3371

MODEL: A	SSE	1013170	F RATIO	25.92
	DFE	68	APPROX PROB	0.0001
DEF VAR: NO	MSE	14899.56	R-SQUARE	0.6957
	OBJ	1156287		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1678.16	3777.891	-0.4442	0.6583
MILLO2	1	35.651581	12.384972	2.8786	0.0053
B001.ROTAT	1	-5.408892	6.273904	-0.8621	0.3916
B001.TEMP	1	3.513842	0.589292	5.9628	0.0001
B001.MAA	1	-4.216423	5.344933	-0.7889	0.4329
COAL	1	-410.148793	107.879014	-3.8019	0.0003
DAMP	1	-12.635436	18.856134	-0.6701	0.5051

MODEL: B	SSE	8.878663	F RATIO	29.10
	DFE	67	APPROX PROB	0.0001
DEF VAR: O2	MSE	0.132517	R-SQUARE	0.7525
	OBJ	15.928498		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	20.535655	7.692050	2.6697	0.0095
B001.MAH	1	0.020790	0.007665902	2.7120	0.0085
B001.MASR	1	-0.339859	0.161807	-2.1004	0.0395
MILLO2	1	0.092533	0.038993	2.3731	0.0205
COAL	1	-1.060811	0.391424	-2.7101	0.0085
B001.MAA	1	0.020020	0.013587	1.4735	0.1453
B001.CO2	1	-0.294819	0.061763	-4.7734	0.0001
DAMP	1	-0.115300	0.054976	-2.0973	0.0397

TABLE 12.

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: AA	SSE	1202110	F RATIO	21.52
	DFE	68	APPROX PROB>F	0.0001
DEP VAR: NOC	MSE	17678.09	R-SQUARE	0.6550
	OBJ	1453617		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	859.969717	4143.694	0.2075	0.8362
MILLO2	1	41.296532	11.855927	3.4832	0.0009
BOO1.ROTAT	1	-3.718716	7.187046	-0.5174	0.6065
BOO1.MAA	1	-14.913241	6.351411	-2.3480	0.0218
BOO1.TEMP	1	3.302029	0.676786	4.8790	0.0001
COAL	1	-404.133004	144.203796	-2.8025	0.0066
BOO1.O2	1	101.136010	38.787816	2.6074	0.0112

MODEL: A	SSE	861620.1	F RATIO	34.43
	DFE	68	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	12670.88	R-SQUARE	0.7523
	OBJ	993929.6		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-327.964586	3508.112	-0.0935	0.9258
MILLO2	1	44.394363	10.037402	4.4229	0.0001
BOO1.ROTAT	1	-4.861243	6.084659	-0.7989	0.4271
BOO1.TEMP	1	3.726697	0.572977	6.5041	0.0001
BOO1.MAA	1	-13.219768	5.377198	-2.4585	0.0165
COAL	1	-432.158479	122.085049	-3.5398	0.0007
BOO1.O2	1	52.112019	32.838334	1.5869	0.1172

MODEL: B	SSE	10.308927	F RATIO	20.68
	DFE	67	APPROX PROB>F	0.0001
DEP VAR: O2	MSE	0.153865	R-SQUARE	0.6836
	OBJ	16.158016		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	22.267826	8.218084	2.7096	0.0085
BOO1.MAH	1	0.011082	0.009525842	1.1634	0.2488
BOO1.MASR	1	-0.367601	0.159695	-2.3019	0.0245
MILLO2	1	0.030470	0.046543	0.6547	0.5149
COAL	1	-0.454144	0.398565	-1.1394	0.2586
BOO1.MAA	1	0.030531	0.016285	1.8747	0.0652
BOO1.CO2	1	-0.273805	0.064129	-4.2696	0.0001
DAMP	1	-0.218697	0.059992	-3.6454	0.0005

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: D	SSE	219.007807	F RATIO	25.54
	DFE	64	APPROX PR>F	0.0001
DEP VAR: ROTAT	MSE	3.421997	R-SQUARE	0.7996
	OBJ	171.321960		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-184.555708	50.100980	-3.6837	0.0005
B001.TEMP	1	0.085392	0.014997	5.6941	0.0001
B001.O2	1	0.584110	0.801790	0.7285	0.4690
B001.NO	1	-0.00992726	0.002976406	-3.3353	0.0014
B001.CO	1	-0.00160149	0.002919741	-0.5485	0.5853
B001.DTEMP	1	-0.042578	0.027212	-1.5647	0.1226
COAL	1	-4.091705	1.877135	-2.1798	0.0330
B001.MAA	1	0.098658	0.070253	1.4043	0.1651
B001.MCO2	1	0.384111	0.069333	5.5401	0.0001
B001.DCO2	1	0.146270	0.164898	0.8870	0.3784
WOOD	1	-133.079341	22.791596	-5.8390	0.0001

MODEL: E	SSE	47962.3	F RATIO	25.72
	DFE	68	APPROX PR>F	0.0001
DEP VAR: TEMP	MSE	705.327900	R-SQUARE	0.6941
	OBJ	45708.67		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	4258.897	355.619854	11.9760	0.0001
B001.MAR	1	2.215906	0.405956	5.4585	0.0001
B001.MAA	1	-4.536536	0.590353	-7.6844	0.0001
B001.MAH	1	-0.572317	0.755832	-0.7572	0.4515
B001.MAF	1	0.831683	0.325993	2.5512	0.0130
B001.MCO2	1	-4.128242	1.201727	-3.4353	0.0010
FLUX	1	-19.046661	7.073698	-2.6926	0.0089

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: G	SSE	1842915	F RATIO	1.20
	DFE	68	APPROX PR>F	0.3174
DEP VAR: CO	MSE	27101.69	R-SQUARE	0.0957
	OBJ	2032608		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1807.39	1874.526	-0.9642	0.3384
B001.TEMP	1	0.881024	0.556750	1.5824	0.1182
B001.ROTAT	1	-7.704689	7.401736	-1.0409	0.3016
B001.O2	1	-67.703118	60.751716	-1.1144	0.2690
B001.MAF	1	-1.957132	1.587684	-1.2327	0.2219
COAL	1	85.325219	137.415059	0.6209	0.5367
MILLO2	1	6.026166	12.494796	0.4823	0.6311

MODEL: H	SSE	55.093655	F RATIO	36.00
	DFE	68	APPROX PR>F	0.0001
DEP VAR: CO2	MSE	0.810201	R-SQUARE	0.7606
	OBJ	98.478254		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1.362286	12.104187	-0.1125	0.9107
B001.MAF	1	0.017024	0.011394	1.4941	0.1398
B001.MAA	1	0.079901	0.023997	3.3296	0.0014
FLUX	1	-0.425331	0.254789	-1.6693	0.0996
B001.MAR	1	0.043406	0.011741	3.6971	0.0004
B001.O2	1	-1.053978	0.328425	-3.2092	0.0020
B001.DCO2	1	0.226274	0.081006	2.7933	0.0068

TABLE 13.
ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1894881	F RATIO	13.56
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	27462.04	R-SQUARE	0.4956
	OBJ	1874435		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	18524.57	2511.938	7.3746	0.0001
MILLO2	1	68.496785	13.041308	5.2523	0.0001
B001.ROTAT	1	20.261279	6.535667	3.1001	0.0028
B001.MAA	1	-38.416792	5.159148	-7.4463	0.0001
COAL	1	-782.759672	151.486677	-5.1672	0.0001
B001.O2	1	62.445025	47.322996	1.3195	0.1913

MODEL: A	SSE	1664878	F RATIO	17.25
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	24128.67	R-SQUARE	0.5556
	OBJ	1529949		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	19608.45	2354.557	8.3279	0.0001
MILLO2	1	75.092786	12.224229	6.1429	0.0001
B001.ROTAT	1	22.202770	6.126187	3.6242	0.0006
B001.MAA	1	-39.746063	4.835911	-8.2189	0.0001
COAL	1	-859.479554	141.995556	-6.0529	0.0001
B001.O2	1	8.445065	44.358060	0.1904	0.8496

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
MAA UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1277664	F RATIO	23.60
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	18516.87	R-SQUARE	0.6310
	OBJ	1551080		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-8238.52	1502.368	-5.4837	0.0001
MILLO2	1	21.262587	8.424878	2.5238	0.0139
B001.ROTAT	1	-13.088863	6.117474	-2.1396	0.0359
B001.TEMP	1	4.507308	0.451416	9.9848	0.0001
COAL	1	-180.949108	110.985753	-1.6304	0.1076
B001.O2	1	106.369621	39.631746	2.6839	0.0091

MODEL: A	SSE	934295.4	F RATIO	37.53
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	13540.51	R-SQUARE	0.7311
	OBJ	1070514		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-8393.28	1284.725	-6.5331	0.0001
MILLO2	1	26.635373	7.204392	3.6971	0.0004
B001.ROTAT	1	-13.167363	5.231255	-2.5171	0.0142
B001.TEMP	1	4.795110	0.386021	12.4219	0.0001
COAL	1	-234.318231	94.907594	-2.4689	0.0160
B001.O2	1	56.751328	33.890419	1.6746	0.0985

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 ROTAT UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1221327	F RATIO	25.74
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	17700.39	R-SQUARE	0.6510
	OBJ	1458350		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	2060.704	3435.082	0.5999	0.5505
MILLO2	1	42.084125	11.765223	3.5770	0.0006
B001.MAA	1	-16.738007	5.285665	-3.1667	0.0023
B001.TEMP	1	3.062552	0.494102	6.1982	0.0001
COAL	1	-431.413079	134.304546	-3.2122	0.0020
B001.O2	1	103.790916	38.471181	2.6979	0.0088

MODEL: A	SSE	881562.8	F RATIO	40.85
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	12776.27	R-SQUARE	0.7475
	OBJ	1002017		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	1241.679	2918.42	0.4255	0.6718
MILLO2	1	45.423935	9.995644	4.5444	0.0001
B001.MAA	1	-15.605169	4.490661	-3.4750	0.0009
B001.TEMP	1	3.413644	0.419785	8.1319	0.0001
COAL	1	-467.820003	114.104122	-4.0999	0.0001
B001.O2	1	55.582611	32.684823	1.7006	0.0935

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1330349	F RATIO	22.24
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	19280.42	R-SQUARE	0.6171
	OBJ	1592462		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-8530.08	2546.083	-3.3503	0.0013
MILLO2	1	15.085413	7.609313	1.9825	0.0514
B001.MAA	1	-3.180426	4.988100	-0.6376	0.5258
B001.TEMP	1	4.322744	0.595719	7.2564	0.0001
B001.ROTAT	1	-11.082895	6.986042	-1.5864	0.1172
B001.O2	1	152.554379	35.689335	4.2745	0.0001

MODEL: A	SSE	1035990	F RATIO	32.75
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	15014.35	R-SQUARE	0.7035
	OBJ	1152699		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-10369.2	2246.816	-4.6151	0.0001
MILLO2	1	16.365578	6.714914	2.4372	0.0174
B001.MAA	1	-0.673315	4.401799	-0.1530	0.8789
B001.TEMP	1	4.818195	0.525698	9.1653	0.0001
B001.ROTAT	1	-12.736107	6.164903	-2.0659	0.0426
B001.O2	1	107.096107	31.494410	3.4005	0.0011

ANALYSIS OF 4-17 (MOD(6)=2) DATA SET USING TWO STAGE LEAST SQUARES.
 O2 UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1496955	F RATIO	19.93
	DFE	69	APPROX PROB>F	0.0001
DEP VAR: NOC	MSE	21694.99	R-SQUARE	0.5909
	OBJ	1573804		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	3852.628	4410.787	0.8735	0.3854
MILLO2	1	54.959422	11.781582	4.6649	0.0001
B001.MAA	1	-15.864908	7.024478	-2.2585	0.0271
B001.TEMP	1	2.941245	0.733909	4.0076	0.0002
B001.ROTAT	1	-6.197692	7.891852	-0.7853	0.4349
COAL	1	-581.986554	140.747719	-4.1350	0.0001

MODEL: A	SSE	945579.2	F RATIO	37.73
	DFE	69	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	13704.05	R-SQUARE	0.7322
	OBJ	1025839		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	1214.052	3505.587	0.3463	0.7302
MILLO2	1	51.434395	9.363716	5.4929	0.0001
B001.MAA	1	-13.710131	5.582885	-2.4557	0.0166
B001.TEMP	1	3.540797	0.583293	6.0704	0.0001
B001.ROTAT	1	-6.138577	6.272253	-0.9787	0.3312
COAL	1	-523.800493	111.862883	-4.6825	0.0001

TABLE 14.

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST 02 ADDED TO THE NO MODEL.

MODEL: AA	SSE	655243.7	F RATIO	40.67
	DFE	68	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	9635.937	R-SQUARE	0.7821
	OBJ	1145744		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-4230.21	2735.844	-1.5462	0.1267
MILLO2	1	26.904328	8.337568	3.2269	0.0019
B001.ROTAT	1	-0.306172	5.213402	-0.0587	0.9533
B001.MAA	1	-6.368320	4.270202	-1.4913	0.1405
B001.TEMP	1	3.404341	0.462320	7.4285	0.0001
COAL	1	-203.563790	113.693419	-1.7905	0.0778
B001.02	1	150.928630	34.112763	4.4244	0.0001

MODEL: A	SSE	773744.5	F RATIO	35.02
	DFE	68	APPROX PR>F	0.0001
DEP VAR: NO	MSE	11378.6	R-SQUARE	0.7555
	OBJ	1082223		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-4767.22	2972.958	-1.6035	0.1135
MILLO2	1	28.193770	9.060179	3.1118	0.0027
B001.ROTAT	1	-0.968893	5.665243	-0.1710	0.8647
B001.TEMP	1	3.658390	0.502389	7.2820	0.0001
B001.MAA	1	-6.300665	4.640297	-1.3578	0.1790
COAL	1	-188.850973	123.547136	-1.5286	0.1310
B001.02	1	98.753283	37.069289	2.6640	0.0096

MODEL: B	SSE	8.878663	F RATIO	29.10
	DFE	67	APPROX PR>F	0.0001
DEP VAR: 02	MSE	0.132517	R-SQUARE	0.7525
	OBJ	15.928498		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	20.535655	7.692050	2.6697	0.0095
B001.MAH	1	0.020790	0.007665902	2.7120	0.0085
B001.MASR	1	-0.339859	0.161807	-2.1004	0.0395
MILLO2	1	0.092533	0.038993	2.3731	0.0205
COAL	1	-1.060811	0.391424	-2.7101	0.0085
B001.MAA	1	0.020020	0.013587	1.4735	0.1453
B001.CO2	1	-0.294819	0.061763	-4.7734	0.0001
DAMP	1	-0.115300	0.054976	-2.0973	0.0397

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: D	SSE	168.287154	F RATIO	35.17
	DFE	64	APPROX PR>F	0.0001
DEP VAR: ROTAT	MSE	2.629487	R-SQUARE	0.8460
	OBJ	161.001311		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-233.798695	45.291648	-5.1621	0.0001
B001.TEMP	1	0.070574	0.012395	5.6937	0.0001
B001.O2	1	-2.292590	0.719527	-3.1862	0.0022
B001.NO	1	-0.00283137	0.002543527	-1.1132	0.2698
B001.CO	1	-0.00469554	0.001568496	-2.9937	0.0039
B001.DTEMP	1	-0.080355	0.021181	-3.7937	0.0003
COAL	1	-2.477039	1.729816	-1.4320	0.1570
B001.MAA	1	0.365526	0.060416	6.0502	0.0001
B001.MCO2	1	0.221899	0.060916	3.6427	0.0005
B001.DCO2	1	-0.523284	0.192013	-2.7253	0.0083
HOOD	1	-111.372754	17.833539	-6.2451	0.0001

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: E	SSE	38400.51	F RATIO	39.86
	DFE	68	APPROX PR>F	0.0001
DEP VAR: TEMP	MSE	564.713380	R-SQUARE	0.7786
	OBJ	37370.92		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	4724.573	313.688643	15.0613	0.0001
B001.MAR	1	2.742738	0.341938	8.0211	0.0001
B001.MAA	1	-5.884892	0.504631	-11.6618	0.0001
B001.MAH	1	0.865704	0.537776	1.6098	0.1121
B001.MAF	1	0.115016	0.263736	0.4361	0.6641
B001.MCO2	1	-5.868900	0.825892	-7.1061	0.0001
FLUX	1	-19.405567	6.011768	-3.2279	0.0019

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
STRUCTURAL EQUATIONS WITH EXHAUST O2 ADDED TO THE NO MODEL.

MODEL: G	SSE	2369305	F RATIO	3.53
	DFE	68	APPROX PR>F	0.0042
DEP VAR: CO	MSE	34842.72	R-SQUARE	0.2376
	OBJ	2716016		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-2630.26	2385.937	-1.1862	0.2397
B001.TEMP	1	1.859820	0.610888	3.0445	0.0033
B001.ROTAT	1	-18.241595	8.349711	-2.1847	0.0324
B001.O2	1	-114.118927	65.262615	-1.7486	0.0849
B001.MAF	1	-2.627551	1.412562	-1.8601	0.0672
COAL	1	19.122114	197.529765	0.0968	0.9232
NILLO2	1	15.772371	13.890012	1.1355	0.2601

MODEL: H	SSE	50.813116	F RATIO	35.35
	DFE	68	APPROX PR>F	0.0001
DEP VAR: CO2	MSE	0.747252	R-SQUARE	0.7572
	OBJ	86.520187		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	13.948134	11.942066	1.1680	0.2469
B001.MAF	1	0.007246617	0.007882794	0.9193	0.3612
B001.MAA	1	0.077862	0.024600	3.1651	0.0023
FLUX	1	-0.722308	0.215145	-3.3573	0.0013
B001.MAR	1	0.030977	0.011576	2.6759	0.0093
B001.O2	1	-1.308974	0.249575	-5.2448	0.0001
B001.DC02	1	0.075423	0.085003	0.8873	0.3780

TABLE 15.

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
TEMP UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1416074	F RATIO	17.73
DEP VAR: NOC	DFE	69	APPROX PR>F	0.0001
	MSE	20522.82	R-SQUARE	0.5624
	OBJ	1677480		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	12968.56	2127.155	6.0967	0.0001
MILLO2	1	47.062908	11.505234	4.0906	0.0001
B001.ROTAT	1	26.445553	5.501474	4.8070	0.0001
B001.MAA	1	-29.839689	4.192110	-7.1181	0.0001
COAL	1	-508.806186	154.707390	-3.2888	0.0016
B001.02	1	140.274246	49.739818	2.8202	0.0063

MODEL: A	SSE	1641564	F RATIO	15.03
DEP VAR: NO	DFE	69	APPROX PR>F	0.0001
	MSE	23790.79	R-SQUARE	0.5213
	OBJ	1685601		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	13553.56	2290.261	5.9179	0.0001
MILLO2	1	49.667456	12.387435	4.0095	0.0002
B001.ROTAT	1	27.528062	5.923318	4.6474	0.0001
B001.MAA	1	-31.303260	4.513554	-6.9354	0.0001
COAL	1	-514.006780	166.570084	-3.0858	0.0029
B001.02	1	87.403828	53.553781	1.6321	0.1072

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
 MAA UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	671890.1	F RATIO	47.86
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	9737.538	R-SQUARE	0.7762
	OBJ	1167176		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-7856.27	1260.818	-6.2311	0.0001
MILLO2	1	20.285712	7.095363	2.8590	0.0056
B001.ROTAT	1	-4.621897	4.359291	-1.0602	0.2927
B001.TEMP	1	3.944503	0.312632	12.6171	0.0001
COAL	1	-134.626896	104.418495	-1.2893	0.2016
B001.02	1	144.791856	34.041725	4.2534	0.0001

MODEL: A	SSE	787651.9	F RATIO	41.52
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	11415.25	R-SQUARE	0.7506
	OBJ	1103202		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-8354.76	1365.119	-6.1202	0.0001
MILLO2	1	21.645469	7.682325	2.8176	0.0063
B001.ROTAT	1	-5.238769	4.719912	-1.1099	0.2709
B001.TEMP	1	4.163133	0.338494	12.2990	0.0001
COAL	1	-120.646449	113.056483	-1.0671	0.2896
B001.02	1	92.681704	36.857816	2.5146	0.0143

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
ROTAT UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	655656.7	F RATIO	49.49
	DFE	69	APPROX PROB>F	0.0001
DEP VAR: NOC	MSE	9502.272	R-SQUARE	0.7820
	OBJ	1145778		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-4148.3	2337.263	-1.7749	0.0803
MILLO2	1	26.892258	8.277023	3.2490	0.0018
B001.MAA	1	-6.507523	3.527218	-1.8449	0.0693
B001.TEMP	1	3.415586	0.331968	10.2889	0.0001
COAL	1	-204.559163	111.640522	-1.8323	0.0712
B001.O2	1	151.465286	32.637303	4.6409	0.0001

MODEL: A	SSE	775756.5	F RATIO	42.53
	DFE	69	APPROX PROB>F	0.0001
DEP VAR: NO	MSE	11242.85	R-SQUARE	0.7359
	OBJ	1082556		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-4508.02	2542.331	-1.7732	0.0806
MILLO2	1	28.155573	9.003235	3.1273	0.0026
B001.MAA	1	-6.741178	3.836690	-1.7570	0.0833
B001.TEMP	1	3.599039	0.361094	9.9670	0.0001
COAL	1	-192.000870	121.435678	-1.5811	0.1184
B001.O2	1	100.451552	35.500847	2.8296	0.0061

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
O2 UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	1214056	F RATIO	24.59
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	17595.01	R-SQUARE	0.6405
	OBJ	1334371		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-1380.84	3593.026	-0.3843	0.7019
MILLO2	1	47.412053	9.364972	5.0627	0.0001
B001.MAA	1	-4.089290	5.728136	-0.7139	0.4777
B001.TEMP	1	3.348339	0.624175	5.3644	0.0001
B001.ROTAT	1	-6.485065	6.787340	-0.9555	0.3427
COAL	1	-530.879106	116.659420	-4.5507	0.0001

MODEL: A	SSE	1020223	F RATIO	31.25
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	14785.83	R-SQUARE	0.6937
	OBJ	1162977		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-2902.86	3293.734	-0.8813	0.3812
MILLO2	1	41.612067	8.584888	4.8471	0.0001
B001.MAA	1	-4.809485	5.250993	-0.9159	0.3629
B001.TEMP	1	3.602119	0.572182	6.2954	0.0001
B001.ROTAT	1	-5.011771	6.221968	-0.8055	0.4233
COAL	1	-403.014860	106.941914	-3.7685	0.0003

ANALYSIS OF 4-17 (MOD(6)=4) DATA SET USING TWO STAGE LEAST SQUARES.
COAL UNCONTROLLED IN THE NO AND NO(CORRECTED) MODELS.

MODEL: AA	SSE	679137.3	F RATIO	47.16
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NOC	MSE	9842.57	R-SQUARE	0.7736
	OBJ	1176635		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-7697.03	1953.407	-3.9403	0.0002
MILLO2	1	15.161400	5.202697	2.9141	0.0048
B001.MAA	1	-3.259801	3.942941	-0.8267	0.4112
B001.TEMP	1	3.733510	0.435666	8.5697	0.0001
B001.ROTAT	1	-1.697702	5.210126	-0.3258	0.7455
B001.O2	1	190.671421	26.179471	7.2832	0.0001

MODEL: A	SSE	795701.9	F RATIO	41.00
	DFE	69	APPROX PR>F	0.0001
DEP VAR: NO	MSE	11531.91	R-SQUARE	0.7482
	OBJ	1108810		

SECOND STAGE STATISTICS

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	APPROX PROB> T
INTERCEPT	1	-7983.47	2114.41	-3.7757	0.0003
MILLO2	1	17.299576	5.631512	3.0719	0.0030
B001.MAA	1	-3.416817	4.267924	-0.8006	0.4261
B001.TEMP	1	3.935936	0.471575	8.3464	0.0001
B001.ROTAT	1	-2.259849	5.639553	-0.4007	0.6899
B001.O2	1	135.623616	28.337222	4.7861	0.0001

APPENDIX 1.
KVB4-17, MOD(6) = 2 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
1	1604	.	.	.	.	.	.	.	.	.	52.1	90.29	2.84	25.38	2.73	108.7	.	78
2	1610	.	.	.	2584	9.48	1770	1584	70	33.0	52.1	90.29	2.84	25.38	2.73	108.7	.	78
3	1616	0.9	21.0	72	2555	9.48	1798	1712	51	30.8	52.1	90.29	2.84	25.38	2.73	108.7	-0.048	78
4	1622	2.1	21.0	72	2564	9.48	1309	1166	694	33.0	52.1	92.41	2.77	25.37	3.02	110.4	-0.048	78
5	1628	0.8	21.0	72	2548	9.48	1669	1624	46	29.1	52.1	92.41	2.77	25.37	3.02	110.4	-0.040	78
6	1634	2.5	21.0	72	2545	9.48	1566	1452	52	30.8	52.1	92.41	2.77	25.37	3.02	110.4	-0.040	78
7	1640	1.6	21.0	72	2542	9.48	1369	1250	54	31.8	52.1	94.53	2.70	25.37	3.31	112.1	-0.040	78
8	1646	1.3	21.0	72	2545	9.48	1424	1349	51	29.9	52.1	94.53	2.70	25.37	3.31	112.1	-0.040	78
9	1652	2.0	21.0	72	2545	9.48	1229	1111	54	32.3	52.1	94.49	2.76	25.97	3.33	113.1	-0.040	78
10	1658	1.1	21.0	72	2548	9.48	1297	1203	42	29.3	52.1	94.50	2.76	25.97	3.33	113.1	-0.040	78
11	1704	1.6	21.0	72	2522	9.48	1423	1286	59	31.6	52.1	94.50	2.76	25.97	3.33	113.1	-0.040	78
12	1710	1.1	21.0	72	2468	9.50	977	849	1551	33.6	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
13	1716	0.3	18.7	72	2515	9.50	1160	1023	81	32.8	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
14	1722	0.6	18.7	72	2531	9.48	1237	1113	62	32.9	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
15	1728	1.0	20.9	73	2527	9.48	1341	1257	43	29.9	49.9	94.50	2.82	24.60	3.35	114.2	-0.055	78
16	1734	1.8	20.9	73	2546	9.48	1277	1143	71	32.2	49.9	92.00	2.80	25.70	2.97	111.3	-0.055	78
17	1740	0.9	20.9	73	2559	9.48	1373	1273	42	30.5	49.9	92.00	2.80	25.70	2.97	111.3	-0.055	78
18	1746	1.6	20.9	69	2579	9.48	1370	1251	47	31.2	49.9	92.00	2.80	25.10	2.97	111.3	-0.055	78
19	1752	1.3	20.9	69	2584	9.48	1461	1348	42	30.9	49.2	89.60	2.78	25.62	2.59	108.4	-0.055	78
20	1758	1.5	20.9	69	2564	9.48	1282	1165	47	31.8	49.2	89.60	2.78	25.62	2.59	108.4	-0.055	78
21	1804	1.2	20.9	69	2541	9.50	1446	1341	39	29.4	49.2	89.60	2.74	25.72	2.68	108.9	-0.055	78
22	1810	1.6	20.9	68	2564	9.50	1289	1154	73	31.5	49.2	90.40	2.74	25.72	2.68	108.9	-0.055	78
23	1816	0.9	20.2	68	2566	9.50	1560	1493	49	28.8	49.2	90.40	2.74	25.72	2.68	108.9	-0.055	78
24	1822	2.2	20.2	68	2561	9.50	1543	1424	51	29.9	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
25	1828	1.5	20.2	68	2561	9.50	1388	1242	71	30.7	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
26	1834	0.9	19.7	68	2579	9.50	1125	1007	186	31.8	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
27	1840	0.9	16.9	68	2583	9.50	1174	1078	64	29.1	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
28	1846	1.4	17.6	68	2584	9.50	1380	1300	55	28.8	49.2	89.72	2.73	25.90	2.57	108.1	-0.040	78
29	1852	1.9	17.6	68	2591	9.50	1152	1031	60	30.9	49.2	89.72	2.73	25.90	2.57	108.1	-0.040	78
30	1858	0.9	13.2	68														80

APPENDIX I.
KVB4-17, MOD(6) = 2 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
31	1904	0.8	14.0	68	2564	9.48	1033	920	78	30.7	49.2	88.30	2.76	26.00	2.36	106.9	-0.04	80
32	1910	0.9	14.2	68	2551	9.50	1127	1009	64	29.9	49.2	88.30	2.76	26.00	2.36	106.9	-0.04	80
33	1916	0.9	14.2	68	2544	9.48	1067	955	58	31.6	49.2	88.30	2.76	26.00	2.36	106.9	-0.04	80
34	1922	0.9	14.2	68	2548	9.48	1051	941	53	31.7	49.2	88.80	2.72	26.20	2.40	107.1	-0.04	80
35	1928	1.1	14.2	68	2548	9.48	1209	1093	41	29.4	49.2	88.80	2.72	26.20	2.40	107.1	-0.04	80
36	1934	1.2	14.2	68	2538	9.48	1192	1083	52	29.3	48.5	89.40	2.68	26.40	2.44	107.3	-0.04	80
37	1940	0.7	14.2	68	2522	9.48	1079	956	322	30.9	45.6	89.40	2.68	26.40	2.44	107.3	-0.04	80
38	1946	1.7	14.2	67	2513	9.48	1294	1206	43	28.4	45.6	89.10	2.66	26.60	2.39	106.6	-0.04	80
39	1952	1.1	14.2	63	2539	9.48	1188	1074	50	29.2	45.6	89.10	2.66	26.60	2.39	106.6	-0.04	80
40	1958	1.0	14.2	63	2548	9.48	1130	1816	41	28.9	45.6	89.10	2.66	26.60	2.39	106.6	-0.04	80
41	2004	1.4	14.2	63	2537	9.48	1138	1045	43	28.9	45.6	88.80	2.64	26.80	2.31	105.9	-0.04	80
42	2010	0.9	14.2	63	2554	9.48	1236	1106	58	28.4	45.6	88.80	2.64	26.80	2.31	105.9	-0.04	80
43	2016	1.0	14.2	63	2562	9.48	1266	1139	43	27.8	45.6	88.30	2.67	26.70	2.27	105.9	-0.04	80
44	2022	0.8	14.2	63	2565	9.48	1361	1212	55	27.9	45.6	88.30	2.67	26.70	2.27	105.9	-0.04	80
45	2028	0.9	14.2	63	2576	9.48	1331	1191	57	28.9	45.6	88.30	2.67	26.70	2.27	105.9	-0.04	80
46	2034	0.9	14.2	63	2580	9.48	1352	1210	41	28.6	45.6	87.90	2.69	26.50	2.23	105.8	-0.04	80
47	2040	1.1	14.2	63	2580	9.48	1425	1288	49	27.7	45.6	87.90	2.69	26.50	2.23	105.8	-0.04	80
48	2046	1.4	14.2	63	2585	9.48	1521	1396	40	26.8	45.6	89.20	2.64	26.70	2.41	106.3	-0.04	80
49	2052	1.6	14.2	63	2589	9.48	1591	1476	28	25.8	45.6	89.40	2.64	26.70	2.41	106.3	-0.04	80
50	2058	0.8	14.2	63	2591	9.48	1544	1375	46	27.7	45.6	90.88	2.60	26.73	2.62	107.3	-0.04	80
51	2104	0.1	14.2	63	2600	9.50	1111	956	1505	28.4	45.6	90.60	2.59	26.90	2.41	106.3	-0.04	80
52	2110	1.2	13.9	63	2593	9.50	1705	1549	40	30.0	45.6	90.60	2.59	26.90	2.41	106.3	-0.04	80
53	2116	1.0	13.7	63	2595	8.91	1780	1601	35	27.3	45.6	92.50	2.56	26.80	2.83	108.4	-0.04	80
54	2122	1.1	13.7	63	2595	8.91	1763	1594	25	27.5	45.6	92.60	2.56	26.80	2.83	108.4	-0.04	80
55	2128	3.6	13.7	63	2573	8.91	1507	1559	26	24.0	44.9	92.50	2.56	26.80	2.83	108.4	-0.04	80
56	2134	3.1	13.6	63	2565	8.91	1575	1584	27	25.6	45.6	94.40	2.52	26.70	3.08	110.0	-0.04	80
57	2140	2.9	13.8	62	2560	8.91	1534	1525	23	26.1	45.6	94.40	2.52	26.70	3.08	110.0	-0.04	80
58	2146	2.3	14.1	63	2547	8.91	1466	1411	30	26.4	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	80
59	2152	3.1	14.5	63	2536	8.91	1216	1223	30	25.2	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	80
60	2158	2.3	13.1	63	2513	8.91	1157	1113	29	26.4	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	80

APPENDIX I.
KVB4-17. MOD(6) = 2 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
61	2204	1.2	13.1	63	2510	8.91	1159	1053	27	28.1	45.6	94.0	2.53	26.70	3.05	109.5	-0.04	82
62	2210	1.7	13.1	63	2505	9.10	974	908	40	27.5	45.6	94.0	2.53	26.70	3.05	109.5	-0.04	82
63	2216	0.4	13.2	63	2497	9.10	839	733	201	30.2	45.6	95.6	2.38	27.70	2.97	109.7	-0.04	82
64	2222	1.7	13.2	63	2487	9.10	916	854	37	27.6	45.6	95.6	2.38	27.70	2.97	109.7	-0.04	83
65	2228	1.2	13.2	63	2470	9.10	960	872	40	28.0	43.4	95.6	2.38	27.70	2.97	109.7	-0.04	83
66	2234	0.6	13.2	63	2466	9.10	939	828	67	29.3	43.4	97.1	2.22	28.80	2.88	109.8	-0.04	83
67	2240	2.4	13.2	60	2490	9.10	1063	1029	28	26.1	43.4	97.1	2.22	28.80	2.88	109.8	-0.04	83
68	2246	1.9	12.5	60	2482	9.10	990	933	31	26.8	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	83
69	2252	1.8	12.6	60	2473	9.10	946	887	29	26.7	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	82
70	2258	1.1	12.6	60	2466	9.29	856	774	29	27.6	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	82
71	2304	1.5	12.6	60	2464	9.29	927	855	39	26.6	44.1	95.6	2.41	27.20	3.14	110.0	-0.04	82
72	2310	2.0	13.6	60	2470	9.29	938	888	41	25.0	44.1	95.6	2.41	27.20	3.14	110.0	-0.04	82
73	2316	1.9	14.5	61	2468	9.48	963	907	29	26.1	44.1	94.9	2.41	27.40	3.02	109.0	-0.08	82
74	2322	2.0	17.0	61	2489	9.48	1081	1024	23	26.3	45.6	94.9	2.41	27.40	3.02	109.0	-0.08	82
75	2328	2.3	15.8	61	2503	9.48	1121	1079	24	26.8	45.6	94.9	2.41	27.40	3.02	109.0	-0.08	82
76	2334	2.3	17.0	63	2511	9.48	1131	1088	28	26.3	49.9	94.3	2.41	27.60	2.89	108.6	-0.08	78
77	2340	1.9	17.0	63	2536	9.48	1187	1118	24	28.6	49.9	94.3	2.41	27.60	2.89	108.6	-0.08	78
78	2346	1.8	17.0	69	2536	9.48	1232	1155	31	28.7	50.6	94.8	2.44	27.20	3.08	109.4	-0.08	78
79	2352	2.5	17.0	69	2540	9.48	1252	1218	30	28.6	52.8	94.8	2.44	27.20	3.08	109.4	-0.08	78
80	2358	2.4	18.0	70	2541	9.48	1254	1213	23	27.7	52.8	94.8	2.44	27.20	3.08	109.4	-0.08	78
81	4	2.3	17.9	73	2525	9.48	1153	1110	30	29.1	44.9	95.6	2.54	26.23	3.34	111.6	-0.08	78
82	10	1.9	17.9	73	2511	9.48	1100	1036	30	28.9	44.9	95.3	2.46	26.80	3.26	110.3	-0.08	78
83	16	2.6	20.9	62	2486	9.50	1255	1228	26	28.0	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
84	22	2.3	20.9	62	2491	9.48	1173	1129	30	30.9	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
85	28	2.3	20.9	62	2486	9.48	954	918	31	29.0	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
86	34	1.7	20.9	62	2460	9.48	965	900	27	31.5	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
87	40	2.9	20.9	62	2436	9.48	991	985	26	29.3	40.5	95.9	2.62	25.70	3.41	112.8	-0.04	78
88	46	2.6	20.9	62	2430	9.48	946	925	33	30.2	39.8	95.9	2.62	25.70	3.41	112.8	-0.04	78
89	52	2.7	20.9	56	2394	9.48	981	965	26	29.0	39.8	92.1	1.59	26.50	2.90	109.5	-0.04	78

APPENDIX 11.
KVB4-17, MOD(6) = 4 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
1	1606	.	.	.	.	.	.	.	.	.	52.1	90.29	2.84	25.38	2.73	108.7	.	78
2	1612	.	.	.	.	.	.	.	.	.	52.1	90.29	2.84	25.38	2.73	108.7	.	78
3	1618	0.5	21.0	72	2566	9.48	1637	1436	212	33.2	52.1	92.41	2.77	25.37	3.02	110.4	-0.048	78
4	1624	1.8	21.0	72	2548	9.48	1683	1579	53	30.3	52.1	92.41	2.77	25.37	3.02	110.4	-0.048	78
5	1630	1.1	21.0	72	2540	9.48	1593	1440	97	31.8	52.1	92.41	2.77	25.37	3.02	110.4	-0.040	78
6	1636	1.3	21.0	72	2555	9.48	1474	1346	53	32.8	52.1	92.41	2.77	25.37	3.02	110.4	-0.040	78
7	1642	1.5	21.0	72	2558	9.48	1489	1374	49	30.9	52.1	92.41	2.77	25.37	3.02	110.4	-0.040	78
8	1648	0.6	21.0	72	2558	9.48	984	868	1597	33.5	52.1	94.53	2.70	25.37	3.31	112.1	-0.040	78
9	1654	1.8	21.0	72	2546	9.48	1470	1378	43	30.4	52.1	94.35	2.70	25.37	3.31	112.1	-0.040	78
10	1700	2.0	21.0	72	2541	9.48	1309	1240	44	30.9	52.1	94.50	2.80	25.97	3.33	113.1	-0.040	78
11	1706	1.6	21.0	72	2541	9.48	1297	1203	42	29.3	52.1	94.50	2.76	25.97	3.33	113.1	-0.040	78
12	1712	0.2	18.7	72	2528	9.50	1181	1921	679	33.6	52.1	94.50	2.80	25.97	3.33	113.1	-0.055	78
13	1718	1.1	18.7	72	2500	9.50	1243	1124	69	32.0	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
14	1724	1.7	17.0	72	2498	9.50	1195	1114	245	32.3	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
15	1730	1.5	20.9	73	2526	9.48	1389	1282	51	30.7	52.8	94.50	2.82	24.60	3.35	114.2	-0.055	78
16	1736	1.9	20.9	73	2531	9.48	1284	1210	44	30.9	49.9	94.50	2.82	24.60	3.35	114.2	-0.055	78
17	1742	2.0	20.9	73	2549	9.48	1441	1365	61	28.9	49.9	92.00	2.80	25.70	2.97	111.3	-0.055	78
18	1748	2.1	20.9	69	2573	9.48	1520	1447	46	30.0	49.9	92.00	2.80	25.70	2.97	111.3	-0.055	78
19	1754	1.4	20.9	69	2582	9.48	1485	1363	59	31.4	49.9	92.00	2.80	25.70	2.97	111.3	-0.055	78
20	1800	1.4	20.9	69	2579	9.48	1459	1339	43	31.3	49.2	89.60	2.78	25.62	2.59	108.4	-0.055	78
21	1806	1.2	20.9	69	2564	9.48	1282	1165	47	31.8	49.2	89.60	2.78	25.62	2.59	108.4	-0.055	78
22	1812	2.0	20.5	68	2561	9.50	1395	1321	41	29.8	49.2	89.60	2.78	25.62	2.59	108.4	-0.055	78
23	1818	1.8	20.2	68	2575	9.50	1429	1339	48	29.8	49.2	90.40	2.74	25.72	2.68	108.9	-0.055	78
24	1824	2.4	20.2	68	2572	9.50	1431	1385	41	27.9	49.2	90.40	2.74	25.72	2.68	108.9	-0.055	78
25	1830	2.3	20.2	68	2567	9.50	1605	1545	49	29.0	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
26	1836	2.0	19.2	68	2579	9.50	1519	1439	47	29.4	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
27	1842	0.8	15.2	68	2577	9.48	1160	1033	66	30.3	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
28	1848	1.0	17.6	68	2584	9.50	1255	1129	62	29.8	49.2	91.20	2.70	25.82	2.77	109.3	-0.040	78
29	1854	0.9	13.6	68	2592	9.50	1152	1031	60	30.9	49.2	89.72	2.73	25.90	2.57	108.1	-0.040	80
30	1900	0.9	13.2	68	2591	9.50	1152	1031	60	30.9	49.2	88.27	2.76	25.99	2.36	106.9	-0.040	80

APPENDIX II.
KVB4-17, MOD(6) = 4 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
31	1906	0.8	14.0	68	2564	9.48	1033	920	78	30.7	49.2	88.30	2.76	26.00	2.36	106.9	-0.04	80
32	1912	0.1	14.2	68	2535	9.50	1062	914	82	31.0	49.2	88.30	2.76	26.00	2.36	106.9	-0.04	80
33	1918	0.5	14.2	68	2546	9.48	1093	939	78	31.1	49.2	88.80	2.72	26.20	2.40	107.1	-0.04	80
34	1924	0.9	14.2	68	2550	9.48	1218	1090	49	29.6	49.2	88.80	2.72	26.20	2.40	107.1	-0.04	80
35	1930	0.4	14.2	68	2541	9.48	1024	894	213	31.9	49.2	89.40	2.68	26.40	2.44	107.3	-0.04	80
36	1936	1.4	14.2	68	2524	9.48	1124	1032	42	29.0	45.6	89.40	2.68	26.40	2.44	107.3	-0.04	80
37	1942	0.7	14.2	68	2519	9.48	1176	1042	52	29.2	45.6	89.40	2.68	26.40	2.44	107.3	-0.04	80
38	1948	1.3	14.2	63	2517	9.48	1164	1063	37	30.0	45.6	89.10	2.66	26.60	2.39	106.6	-0.04	80
39	1954	0.6	14.2	63	2552	9.48	1109	978	56	30.2	45.6	89.10	2.66	26.60	2.39	106.6	-0.04	80
40	2000	1.4	14.2	63	2537	9.48	1138	1045	43	28.9	45.6	88.80	2.64	26.80	2.31	105.9	-0.04	80
41	2006	0.9	14.2	63	2554	9.48	1236	1106	58	28.4	45.6	88.80	2.64	26.80	2.31	105.9	-0.04	80
42	2012	1.7	14.2	63	2556	9.48	1346	1255	38	27.4	45.6	88.80	2.64	26.80	2.31	105.9	-0.04	80
43	2018	0.8	14.2	63	2563	9.48	1278	1138	73	28.1	45.6	88.30	2.67	26.70	2.27	105.9	-0.04	80
44	2024	0.9	14.2	63	2570	9.48	1320	1181	38	29.1	45.6	88.30	2.67	26.71	2.27	105.9	-0.04	80
45	2030	1.1	14.2	63	2579	9.48	1450	1311	50	27.4	45.6	88.30	2.67	26.70	2.27	105.9	-0.04	80
46	2036	0.9	14.2	63	2580	9.48	1352	1210	41	28.6	45.6	87.90	2.69	26.50	2.23	105.8	-0.04	80
47	2042	1.7	14.2	63	2582	9.48	1485	1384	35	27.5	45.6	87.90	2.69	26.50	2.23	105.8	-0.04	80
48	2048	0.2	14.2	63	2588	9.50	1185	1025	600	28.5	45.6	89.20	2.64	26.70	2.41	106.3	-0.04	80
49	2054	0.1	14.2	63	2590	9.50	1097	944	1061	28.3	45.6	89.40	2.64	26.70	2.41	106.3	-0.04	80
50	2100	1.2	14.2	63	2593	9.48	1679	1526	39	26.7	45.6	92.51	2.60	26.77	2.83	108.4	-0.04	80
51	2106	0.1	14.2	63	2600	9.50	1111	956	1505	28.4	45.6	90.60	2.59	26.90	2.41	106.3	-0.04	80
52	2112	1.2	13.9	63	2595	9.50	1755	1595	38	27.2	45.6	90.60	2.59	26.90	2.41	106.3	-0.04	80
53	2118	0.3	13.7	63	2593	8.90	1466	1274	119	28.6	45.6	92.50	2.56	26.80	2.83	108.4	-0.04	80
54	2124	3.6	13.7	63	2584	8.91	1639	1696	33	24.0	44.9	92.50	2.56	26.80	2.83	108.4	-0.04	80
55	2130	3.4	13.7	63	2571	8.91	1528	1563	20	24.1	44.9	92.50	2.56	26.80	2.83	108.4	-0.04	80
56	2136	2.8	13.7	62	2554	8.91	1581	1564	23	25.5	45.6	94.40	2.52	26.70	3.08	110.0	-0.04	80
57	2142	2.6	13.9	62	2567	8.91	1509	1476	25	26.1	45.6	94.40	2.52	26.70	3.08	110.0	-0.04	80
58	2148	2.5	14.4	63	2545	8.91	1392	1354	22	26.0	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	80
59	2154	2.3	13.6	63	2530	8.91	1185	1140	27	27.2	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	80
60	2200	2.1	13.1	63	2510	8.91	1185	1128	30	26.9	45.6	94.20	2.53	26.70	3.06	109.8	-0.04	82

APPENDIX 11.
KVB4-17, MOD(6) = 4 DATA SUBSET.

OBS	TIME	O2	MILLO2	ROTAT	TEMP	COAL	NO	NOC	CO	CO2	METH2	LSF	SR	FLUX	BURNI	BURNF	HOOD	DAMP
61	2206	1.7	13.1	63	2503	9.10	974	908	40	27.5	45.6	94.0	2.53	26.70	3.05	109.5	-0.04	82
62	2212	1.4	13.2	63	2503	9.10	947	869	34	28.7	45.6	94.0	2.53	26.70	3.05	109.5	-0.04	82
63	2218	1.5	13.2	63	2496	9.10	916	845	52	28.4	45.6	95.6	2.38	27.70	2.97	109.7	-0.04	83
64	2224	0.8	13.2	63	2475	9.10	877	781	307	29.3	43.4	95.6	2.38	27.70	2.97	109.7	-0.04	83
65	2230	1.7	13.2	63	2468	9.10	990	923	26	27.7	43.4	95.6	2.38	27.70	2.97	109.7	-0.04	83
66	2236	2.5	13.2	60	2479	9.10	1073	1044	22	25.1	43.4	97.1	2.22	28.80	2.88	109.8	-0.04	83
67	2242	1.9	13.2	60	2492	9.10	1104	1040	29	26.2	43.4	97.1	2.22	28.80	2.88	109.8	-0.04	83
68	2248	2.1	12.5	60	2482	9.10	1004	956	24	26.0	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	83
69	2254	2.3	12.6	60	2470	9.29	888	855	24	25.9	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	82
70	2300	1.4	12.6	60	2465	9.29	876	804	31	26.9	43.4	96.4	2.32	28.00	3.01	109.9	-0.04	82
71	2306	1.7	12.6	60	2466	9.29	916	854	34	26.2	44.1	95.6	2.41	27.20	3.14	110.0	-0.04	82
72	2312	2.0	13.6	60	2470	9.29	941	891	36	26.0	44.1	95.6	2.41	27.20	3.14	110.0	-0.08	82
73	2318	1.7	14.0	61	2473	9.48	961	896	25	27.0	44.1	94.9	2.41	27.40	3.02	109.0	-0.08	82
74	2324	1.8	16.3	61	2496	9.48	1039	974	24	27.2	45.6	94.9	2.41	27.40	3.02	109.0	-0.08	82
75	2330	1.8	15.8	61	2505	9.48	1102	1033	23	28.2	45.6	94.9	2.41	27.40	3.02	109.0	-0.08	82
76	2336	2.2	17.0	63	2500	9.48	1160	1110	24	26.2	49.9	94.3	2.41	27.60	2.89	108.6	-0.08	78
77	2342	1.9	17.0	63	2536	9.48	1187	1118	24	28.6	49.9	94.3	2.41	27.60	2.89	108.6	-0.08	78
78	2348	1.8	17.0	69	2536	9.48	1232	1155	31	28.7	52.8	94.8	2.44	27.20	3.08	109.4	-0.08	78
79	2354	1.3	17.0	69	2541	9.48	1178	1076	26	29.2	52.8	94.8	2.44	27.20	3.08	109.4	-0.08	78
80	0	1.5	18.0	73	2536	9.48	1202	1109	29	29.7	44.9	95.6	2.54	26.23	3.34	111.6	-0.08	78
81	6	1.9	17.9	73	2511	9.48	1100	1036	30	28.9	44.9	95.6	2.54	26.23	3.34	111.6	-0.08	78
82	12	2.7	20.9	62	2486	9.50	1219	1199	29	27.9	44.9	95.3	2.46	26.80	3.26	110.3	-0.04	78
83	18	1.8	21.0	62	2486	9.50	1205	1129	30	30.1	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
84	24	1.6	20.9	62	2493	9.48	1030	955	50	30.4	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
85	30	2.1	20.9	62	2480	9.48	943	898	27	29.6	44.9	95.6	2.54	26.20	3.34	111.6	-0.04	78
86	36	2.7	20.9	62	2452	9.48	1069	1051	29	28.8	44.9	95.9	2.62	25.70	3.41	112.8	-0.04	78
87	42	2.6	20.9	62	2430	9.48	946	925	33	30.2	39.1	95.9	2.62	25.70	3.41	112.8	-0.04	78
88	48	1.2	20.9	62	2392	9.48	926	841	32	30.7	39.8	95.9	2.62	25.70	3.41	112.8	-0.04	78
89	54	2.8	20.9	54	2400	9.48	946	936	25	28.2	39.8	92.1	1.59	26.50	2.90	109.5	-0.04	78

APPENDIX I

QUALITY ASSURANCE - INTERNAL AUDIT



TECHNICAL MEMORANDUM

TO: R. Benson
FROM: R. D. Griffin
SUBJECT: QUALITY ASSURANCE - EPA
COPIES: S. Cherry

DATE: February 2, 1984
NO.: TM71-R-1133

On two occasions the KVB project QA officer ran QA audits on the KVB test team while they were testing the cement kiln at . . . This memo documents the results of those audits.

The first audit was run on October 12, 1983, and consisted of a field accuracy check on the NOx emissions data from the test van and a field check on the accuracy of the NOx calibration gas cylinders. Table 1 summarizes the results of this first audit. Triplicate EPA Method 7 samples were used as the reference to which the other data were compared. Copies of the lab analyses and field reports are also attached.

For the lower cal gas a difference of +58 ppm was found which corresponds to a +10.6% deviation from reference. The higher cal gas showed a +86 ppm difference, or a deviation of +7.7%. Both of these values are within the designated QA objective of 20% accuracy.

Simultaneous sampling of the flue gas in parallel with the van data was performed with the reference method. The NOx data were both corrected to 3% O₂ to account for differences in observed O₂ levels in the Method 7 sample. Using the corrected NOx values, the test data by the instrumented van was low by 89 ppm or a -11% deviation. This, however, was well within the QA objective of 20%.

The second audit was performed on November 17, 1983, and consisted of a field audit of the N₂ injection test; specifically, the % O₂ in the diluent N₂ gas stream. A copy of the Engineering Division Field Report is attached. This report indicates that there was an on-site change in the frequency of data logging the O₂ readings (from one minute to two minutes/data point), but that this was considered acceptable due to the long test period (3 hrs) and

R. Benson
TN71-R-1133

February 2, 1984
Page 2

the stability of the O₂ levels. The site-specific QA completeness objective of 85% for this data was met on both test occasions when 100% of the test data points were logged.

A handwritten signature in cursive script, appearing to read "Roger D. Griffin", is written over a horizontal line.

RDG:gc

Attachments: As Noted

TABLE 1. NOx ACCURACY TEST: CAL GASES AND FIELD ACCURACY

Condition	Flask No.	EPA Method 7		Test Value	Test Value, Dif. from Ref.	
		ppm NOx	ppm NOx at 3% O ₂		ppm	%
Cal gas cyl #A-2063	1350	554	---	605.9 ppm NOx 29.96% CO ₂	+58	+10.6
	1037	551	---			
	1448	<u>538</u>	---			
	Avg	548				
Cal gas cyl #AAL-8349	1127	1093	---	1200 ppm NOx 22.0% CO ₂	+86	+ 7.7
	1413	1141	---			
	1327	<u>1108</u>	---			
	Avg	1114				
Rotary kiln dust box sample	1451	172	794	Test van data: 718 ppm at 3% O ₂	-89	-11.0
	3003	227	851			
	1464	142	<u>775</u>			
	Avg		807			



Date 10/12/83

Engineer _____

ROGER GRIFFIN

NOX AUDIT - FIELD SAMPLES

[illegible]



Date 10/12/83

Engineer Roger Griffin

during BASELINE

RE Due To MISS Testing
INSTRUMENTATION FOR NIXOL
Observations

I-6

REPORT

TRUESDAIL LABORATORIES, INC.

CHEMISTS - MICROBIOLOGISTS - ENGINEERS
RESEARCH - DEVELOPMENT - TESTING



14201 FRANKLIN AVENUE
TUSTIN, CALIFORNIA 92680
AREA CODE 714 • 730-6239
AREA CODE 213 • 225-1864
CABLE: TRUELABS

CLIENT KVB Incorporated
Post Office Box 19518
Irvine, California 92711
Attention: Roger Griffin

DATE November 2, 1983

RECEIVED October 17, 1983

SAMPLE 9 PDSA Flasks

LABORATORY NO. 51563

P.O. NO. 27827

INVESTIGATION

Nitrogen oxides, oxygen and carbon dioxide.

RESULTS

The submitted samples were analyzed for nitrogen oxides (NO_x) by the phenoldisulfonic acid (PDSA) method and for oxygen (O_2) and carbon dioxide (CO_2) by Orsat.

The results are as follows:

<u>Flask No.</u>	<u>CO₂, %</u>	<u>O₂, %</u>	<u>Nitrogen Oxides</u>	
			<u>ppm DRY</u>	<u>@ 3% O₂</u>
1451	5.8	17.1	172	794
3003	7.4	16.2	227	851
1464	<u>5.1</u>	<u>17.7</u>	<u>142</u>	<u>775</u>
Average	6.1	17.0	180	807

1448	538
1037	551
1350	<u>554</u>
Average	548

1413	1141
1127	1093
1327	<u>1108</u>
Average	1114



Respectfully submitted,

TRUESDAIL LABORATORIES, INC.

S. Hugh Brown

S. Hugh Brown, Supervisor
Air Pollution Testing



ENGINEERING DIVISION...FIELD REPORT

NAME OF APPLICANT

CALIFORNIA CEMENT - N₂ INJECTION

#806030

DATE
11/17/83

KVB STAFF MANNING STATIONS AT N₂ INJECTION POINT, PRIMARY AIR PIPE, CONTROL ROOM, INSTRUMENT VAN, AND AT BURNER.

PRIMARY AIR O₂ MEASUREMENTS MADE IN ACCORDANCE WITH SITE QA. PLAN → O₂ MEAS. AT ONE MINUTE INTERVALS & PERIODIC O₂ SPAN ON AIR.

INITIAL N₂ INJECTION APPARENTLY REDUCES MIX, BUT MIX SWINGS INDEPENDENT OF N₂ INJECTION - O₂ AT PRIMARY AIR = 15.5%.

DUE TO LENGTH OF TESTS, PRIM. AIR O₂ READINGS TAKEN EVERY 2 MINUTES SINCE O₂ IS VERY CONSTANT DURING TEST.

IN TWO HALF HOUR TESTS, WITH READINGS EVERY TWO MINUTES LOGGED BY JIM WALKER (TECHNICIAN), 100% OF THE REQUIRED TEST POINTS (15) WERE MADE. QA. OBJECTIVE OF COMPETENCE WAS ACHIEVED.

CALIBRATIONS OF THE O₂ ANALYZER WERE MADE BEFORE AND AFTER EACH TEST SEQUENCE. SPAN DRIFT USING AMBIENT AIR AS THE CAL WAS ≤ 0.1% FOR EACH TEST.

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SIGNATURE

PAGE 1 OF 1 PAGES

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